SETTING REALISTIC OBJECTIVES: VEGETATION INVENTORY AND MONITORING AT SHENANDOAH NATIONAL PARK

Duane R. Diefenbach[1] and Carolyn Mahan[2]

Technical Report NPS/PHSO/NRTR-02/087

[1]Assistant Unit Leader
Pennsylvania Cooperative Fish and Wildlife Research Unit
U.S. Geological Survey, Biological Resources Division
Pennsylvania State University
University Park, PA 16802

[2]Assistant Professor of Biology
Pennsylvania State University
Altoona College
Altoona, PA 16601

Betsie Blumberg - Content Editor
Emily Hill - Formatting Editor

June 2002

Cooperative Agreement No. CA4000–8–9028
Supplemental Agreements 8 and 16

National Park Service
Northeast Region, Philadelphia Support Office
Stewardship and Partnerships
200 Chestnut Street
Philadelphia, PA 19106

Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

The National Park Service is committed to inventorying and monitoring the natural resources under its stewardship. The work reported here contributes to the refinement of the process of data collection so that it can provide the specific information needed for the optimal management of those resources.

In March of 2000, a group of natural resource experts met to develop objectives for Shenandoah National Park's Vegetation Inventory and Monitoring Program. This report combines two papers about that project. Carolyn Mahan, Assistant Professor of Biology at Penn State University, reported on the workshop itself, which resulted in the identification of specific management and sampling objectives in three areas of interest: general forest trends, (e.g., tree species composition and tree growth rates.), forest health (e.g., trends in hemlock woolly adelgid infestation), and special and unique ecosystems and species (e.g., trends in abundance of endangered plant species).

Duane Diefenbach, U.S. Geological Survey, Pennsylvania Cooperative Fish and Wildlife Research Unit, conducted a statistical evaluation of vegetation data collected at the park from 1997 through 2000 to determine whether the objectives stated at the workshop could be met, and recommended adjustments to the sampling design.

The data used in the evaluation were collected as part of the park's Long Term Ecological Monitoring System (LTEMS) program from 1987 to 2000 to estimate basal area (m^2/ha) of trees (>5 m tall), stem density (stems/ha) of shrubs and saplings (1-5 m tall), and stem density (stems/ha) of seedlings (woody vegetation <1 m tall). Also, data collected at the Big Meadows site were used to estimate changes in shrub coverage before and after treatment by burning. The coefficient of variation (CV = standard error/mean x 100%) was used as a measure of the precision of an estimate. A CV $\leq$ 10% is generally considered necessary for research, a CV $\leq$ 25% is recommended for management, and a CV $\cong$ 50% is usually sufficient for pilot studies. The species for which basal area and stem density were calculated were determined in consultation with park staff. All forest cover types were sampled $\geq$2 times during 1987-2000, although they were not sampled during the same year such that parkwide estimates for any given year could be calculated. These data provided variances that were incorporated into a power analysis to assess whether the current LTEMS and Big Meadows sampling designs could meet stated inventory and monitoring objectives.

The following objectives, established during the workshop, were evaluated:

1. Data collected for the LTEMS program should ensure a 90% probability of detecting a $\geq$50% change in the basal area or stem density of any woody plant species (in a given size class) within any one forest cover type over a five-year period (α =0.20). The ability of current sampling efforts to meet this objective were assessed by calculating power curves for tree basal area, shrub and sapling stem density, and seedling stem density.

2. Data collected for the LTEMS program should ensure an 80% probability of detecting a $\geq$20% change in the coverage of a particular exotic species parkwide over a five-year period (α =0.20). The ability of the current LTEMS program at Shenandoah NP to meet this objective was assessed using the power curves calculated above for changes in seedling and sapling stem density of tree-of-heaven (*Ailanthus altissima*). Stem density was used as an indicator of areal coverage for this species.

3. Data collected for the LTEMS program should ensure an 80% probability of detecting a $\geq$20% change parkwide in species affected by disease or insects over a five-year period (α =0.20). The ability of the current LTEMS program at Shenandoah NP to meet this objective was assessed using the power curves calculated above for changes in stem density of flowering dogwood (*Cornus florida*) and basal area of all oak species.

4. Monitoring of shrub coverage at Big Meadows should ensure a 95% probability of detecting a $\geq$40% reduction in shrub coverage over a five-year period (α =0.15). The program TRENDS was used to estimate the statistical power to detect these changes.

For basal area, most CVs were <40% for species in forest cover types where they were dominant (e.g., northern red oak [*Quercus rubra*] in northern red oak cover types). Declines in oaks and the decline of Virginia pine (*Pinus virginiana*) and pitch pine (*Pinus rigida*) were evident from the changes in estimated basal area between sampling periods. Because most basal area measurements are >20 m^2/ha for species in their primary forest cover types (e.g., yellow poplar in cove hardwoods, northern red oak in chestnut oak cover type, etc.), current sampling effort should have $\geq$90% power to detect changes in basal area of 50% for dominant species.

For stem density of shrubs and saplings, most CVs were >50% (range 31-1,169%). The power analysis suggested that stem density changes of $\geq$2,000 stems/ha had >90% probability of being detected. Because most stem densities during both sampling periods were <1,000 stems/ha, current sample sizes are inadequate to detect important changes in stem density of shrubs and saplings.

Stem density of seedlings was extremely variable, and the power analysis suggested that only extremely large changes in stem density (>70,000 stems/ha) could be detected under the current sampling effort. Moreover, large enough sample sizes likely cannot be obtained to meet stated objectives because of the inherent variability of these data.

Increases in stem density for tree-of-heaven >1m tall (sapling) ranged from 0-143 stems/ha (Appendix G). The ability to detect such changes is poor (power < 70%) even if sample sizes were tripled.

Shrub stem densities for flowering dogwood ranged from 15.7 to 536.1 stems/ha. Under current sampling efforts, power was estimated as >80% for changes >1,000 stems/ha. Consequently, the sampling effort would have to increase 2-3 times current levels to detect ~100% changes in current densities.

The effect of gypsy moth on oak abundance, as measured by changes in basal area for all oak species, has a good chance of being detected under current sample sizes. Mean stem densities of oak saplings ranged from 0 to 871 stems/ha, and thus the ability to detect only large changes in stem densities (>1,000 stems/ha) for saplings will likely have acceptable power.

The current sampling design for Big Meadows provided estimates of total shrub coverage (all species combined) and of changes in shrub coverage, with CVs < 20%. Although estimates of coverage for individual shrub species were not precise (CVs > 30%), biologically important changes in overall shrub coverage should be detected under the current sampling design.

To meet the monitoring objectives developed at the workshop, recommendations for the most important changes to the LTEMS program at Shenandoah NP are listed here. Additional recommendations are detailed in the report.

1. A sampling design needs to be implemented that will permit parkwide estimates of vegetation parameters for a given point in time. Presently, changes in basal area or stem density can be estimated within each forest cover type, but cannot be estimated across all cover types for the same time period because each forest cover type is visited in a different year.

2. Requirements to monitor the spatial distribution of forest cover types should be investigated before implementing changes to the sampling design. Traditional stratified sampling designs cannot incorporate changes in the distribution of cover types over time.

3. Sample sizes need to be increased such that all strata contain >1 plot. Sample sizes overall may need to be increased, depending on the selected sampling design, to meet objectives for detecting changes in stem density of shrubs and saplings.

4. Trees within plots should continue to be permanently marked with unique identifiers to reduce misidentification and data collection errors.

5. An electronic field-based data entry system should be fully implemented to speed data collection, reduce data entry errors, and eliminate transcription errors that may occur with a paper system.

6. The purpose and need to collect seedling stem densities should be reviewed. It is unlikely that it will be possible to obtain adequate sample sizes to detect biologically important changes in seedling density or abundance.

Introduction

More than a decade ago, Shenandoah National Park (NP) established a program "Long-Term Ecological Monitoring System" (LTEMS) as the basis for the park's natural resource management program. In practice and theory, the LTEMS program should provide the data necessary for the fundamental understanding of ecological processes and changes that occur within the park. The overall goals of the LTEMS program (Smith and Torbert 1990, Shenandoah NP 1991) are to 1) obtain and maintain a scientifically-based understanding of the type, abundance, and distribution of natural resources, 2) monitor resource condition and changes through time, and 3) monitor natural processes and anthropogenic influences that maintain or affect ecosystem health.

In evaluating this monitoring program, an initial step was to choose several examples within the monitoring program and test the statistical power of these data to detect specific trends (Gibbs 1998). The outcome of this work suggested that a more formal evaluation of the program was needed to ensure that stated objectives were being met.

Consequently, on March 21, 2000, a one-day workshop was held at the park headquarters in Luray, Virginia. The objective of the workshop was to develop specific, appropriate, measurable, and statistically precise objectives for Shenandoah National Park's Vegetation Inventory and Monitoring Program. Fifteen participants from ten organizations participated in the workshop (Table 1). Organizations included universities and non-governmental and governmental agencies.

The purpose of the workshop was not to design an inventory and monitoring program. Rather, the workshop participants were asked to assist resource managers at the park in determining what to inventory and monitor and what sort of trends and status they should be able to detect. Monitoring efforts were to be linked to *specific* management and sampling objectives as well as to sound sampling methodology.

Management objectives reflect the outcome or finding resource managers would like to see as a result of a particular management activity or monitoring program. Sampling objectives are more specific and link management objectives to a degree of statistical rigor, including alpha-levels and statistical power. It is imperative that specific management and sampling objectives be formulated so that the success of the program can be periodically measured and modified if necessary. Without clarifying objectives *a priori*, researchers often end up with data that address the wrong question(s), too much or too little data, or data that are of no use (Gibbs, 1998). Finally, selecting specific and appropriate objectives reduces the cost and increases the effectiveness of the LTEMS program.

Table 1. Participants at Vegetation Monitoring Workshop, Shenandoah National Park, Luray, Virginia, March 21, 2000.

Name	Area/Title	Affiliation	Email	Phone
John Young	GIS Specialist	USGS Biological Resources Division, Leetown Science Center	John_A_Young@usgs.gov	304-724-4469
Dave Maddox	Ecologist	The Nature Conservancy	gdmaddox@aol.com	202-232-6625
James Akerson	Forest Health Specialist	Shenandoah National Park	James_Akerson@nps.gov	540-999-3496
Tom Blount	Supervisor Ecologist	Shenandoah National Park	Tom_Blount @nps.gov	540-999-3497
Wendy Cass	Botanist	Shenandoah National Park	Wendy_Cass@nps.gov	540-999-3432
John Scrivani	Forest Ecologist	Virginia Department of Forestry	scrivanij@dof.state.va.us	804-977-6555
Dave Smith	Forest Ecologist	Virginia Tech	smithdwm@vt.edu	540-231-8862
Shep Zedacker	Forest Ecologist	Virginia Tech	zedaker@vt.edu	540-231-4855
Duane Diefenbach	Biometrician	USGS, PA Coop. Fish & Wildlife Unit, Penn State	drd11@psu.edu	814-865-4511
John Karish	Chief Scientist	National Park Service	John_Karish@nps.gov	814-865-7974
Carolyn Mahan	Biologist	Penn State	cgm2@psu.edu	814-949-5530
Kevin Heffernan	Ecologist	Virginia Natural Heritage Program	keheffernaaan@dcr.state.va.us	804-786-9112
Bill Burkman	Forest Health Specialist	US Forest Service	bburkman/srs_fia@fs.fed.us	828-259-0522
Paul Geissler	Statistician/Scientist	USGS Biological Resources Division, Pautuxent Research Center	paul_geissler@usgs.gov	301-497-5780
Sam Droege	Statistician/Scientist	USGS Biological Resources Division, Pautuxent Research Center	frog@usgs.gov	301-497-5840

Procedures for Developing Specific Objectives

The workshop began with brief synopses from the National Park Service, U.S. Forest Service, and The Nature Conservancy that outlined each organizations' programs for establishing, conducting, and evaluating the inventorying and monitoring of plants. More specifically, workshop participants focused on clarifying the overall goals and objectives of the National Park Service and Shenandoah NP, in particular, so that management and sampling objectives could be developed. Prior to the workshop, three areas of interest were identified by resource managers at the park to focus their vegetation inventorying and monitoring activities. These areas were:

1. Inventorying and monitoring <u>general forest trends</u>: This includes collecting baseline data and understanding and comparing forest trends at Shenandoah NP in a regional (Mid-Atlantic) context.

2. Inventorying and monitoring <u>forest health</u>. This includes maintaining native plant species within the park and striving to keep it free of exotic plants, animals, and diseases. Furthermore, maintaining forest health involves limiting other anthropogenic effects to the forest, e.g, visitor trampling, air pollution, and artificially high numbers of white-tailed deer.

3. Inventorying and monitoring <u>special and unique ecosystems and species</u> located within the park. This includes determining what unique ecosystems, communities, and species are present at Shenandoah NP and monitoring changes in their status.

To further focus management and sampling objectives in each of these areas, workshop participants were asked to determine what degree of change they want to measure or detect, what sites at Shenandoah NP are high priority, and what forest health issues are of particular importance.

General Forest Trends

Participants in this group were Tom Blount, Dave Smith, Sam Droege, Shep Zedacker, John Scrivani, Paul Geissler, and John Young (for affiliation and contact information, see Table 1). This group identified two kinds of information needed for inventorying and monitoring general forest trends:

- The changes in forest vegetation composition and structure throughout the park and in a regional context over time. (Vegetation composition refers to species composition and vegetation structure refers to the distribution of sizes and dominance as determined by height and dbh (diameter at breast height).

- Spatial distribution of changes in forest cover types (mapping exercise).

In order to meet the identified needs for inventorying and monitoring forest health, this group recommended collecting data and performing data analysis exercises in three areas. This group felt it was important to maintain some continuity in data measures that are already being collected as part of the on-going LTEMS program at Shenandoah NP. The three areas of data collection are as follows:

1. Baseline data:
   Primary data
   - Woody vegetation compostion (species richness)
   - Woody vegetation structure
     Dbh, basal area, and height of all dominant and co-dominant overstory trees
     Dbh of all woody plants greater than 0.5 m in height
   - Crown health

   Secondary data
   - Presence/absence and number of stems of non-woody exotic plants
   - Number of non-woody native plants

2. Site characteristics (physical variables):
   - Age of overstory trees
   - Soils
   - Aspect
   - Elevation
   - Topography

3. Broad-scale mapping of landform and forest cover types within the park:
   - Re-map the park based on landform types (in addition to the forest cover type maps currently used at the park)
   - Stratify sites based on landform categories. Landform categories will not change as rapidly over time and can be correlated with vegetation changes.
   - Overlay the U.S. Forest Service's Forest Inventory and Analysis (FIA) plots, current LTEMS plots, and landform categories in the park. Determine the landforms within which the current plots (FIA and LTEMS) are found and select additional landform sites to fill in gaps.

Objectives for General Forest Trends

This group identified three management and sampling objectives that could be used to assess general forest trends.

1. These objectives relate to spatial area coverage for forest cover types in the park. The spatial coverage of a forest cover type is based on basal area.

Management Objective: To be able to detect a 20% change in spatial area coverage of any one forest cover type (e.g., hemlock, yellow poplar) over a five-year period.

Sampling Objective: To be 90% sure of detecting a 20% change in the spatial area coverage of any one forest cover type over a five-year period and are willing to accept a 2-in-10 chance that we determine that a change took place when it really did not.

2. These relate to forest regeneration. The measurement of regeneration is based on the number of stems per acre and the change in density of different species of dominant and codominant trees over time within a forest cover type. Variation in the number of stems per acre is usually high and dependent on stand dynamics. In addition, when focusing on a particular species within a cover type, the investigator must keep in mind that the density of one species is not independent of the density of another.

Management Objective: To be able to detect a 50% change in the density of any one species of tree (dominant or codominant) within any one forest cover type over a five- year period.

Sampling Objective: To be 90% sure of detecting a 50% change in the density of any one species of tree (dominant or codominant) within any one forest cover type over a five-year period and are willing to accept a 2-in-10 chance that we determine that a change took place when it really did not.

3. These objectives relate to the accuracy of the mapping of forest cover types to represent the actual spatial coverage of a forest cover type at Shenandoah NP.

Management Objective: The forest cover type maps should accurately reflect the true forest coverage.

Sampling Objective: To be 90% confident that the classification of any one forest cover type is within 20% of the estimated true value.

Forest Health

Participants in this group were James Akerson, Bill Burkman, Duane Diefenbach, and John Karish (for affiliation and contact information, see Table 1).

This group identified the following threats as potential items to inventory and monitor to assess forest health. Specific data to be collected are listed under each threat.

1. Air pollution
    - For ozone:
        - Number of sensitive species present or absent
        - Number of leaves affected by ozone injury
        - Severity of affected leaves
        - Focus monitoring on species that are easy detect (e.g., low growing)
2. For sulfur/nitrogen pollution:
    - Species composition of lichen communities
    - Number of sensitive lichen species present or absent
    - Bioanalysis of collected lichen specimens

After much discussion, the entire group of participants recommended that direct measures of air quality are better indicators of the threat of air pollution to forest health than indirect measures of plant or lichen health.

2. Invasive Exotics

For plants, inventory and monitor presence or absence and rate of spread for the following plants:

- Bittersweet
- Kudzu
- Honeysuckle
- Garlic mustard
- Stilt grass
- *Ailanthus*
- *Paulownia*

For animals:

- Presence or absence of hemlock woolly adelgid on hemlocks
- Hemlock crown health
- Presence or absence of gypsy moth on trees
- Number of gypsy moth egg cases
- Aerial defoliation surveys for gypsy moth damage
- Presence or absence of Asian longhorn beetle

For diseases:

- Number of trees showing symptoms of infection by dogwood anthracnose
- Number of trees showing symptoms of infection by beech bark disease

3. Other threats to forest health (specific data measures not identified)

- Visitor trampling
- White-tailed deer herbivory and abundance

<u>Objectives for Forest Health</u>

This group identified one management and sampling objective that could be used to assess forest health at Shenandoah NP. These relate to the control of exotics. Resource managers are particularly interested in learning whether they are successful in reducing the acreage of particular species of exotic plants over a set time period.

Management Objective: To detect a 20% decrease in the acreage of a specific exotic plant species (e.g., Ailanthus) parkwide from 2000-2005.

Sampling Objective: To be 80% sure of detecting a 20% change in the coverage of a particular exotic species parkwide from between 2000 and 2005 and accept a 2-in-10 chance that a change took place when it really did not.

Special and Unique Ecosystems and Species

Participants in this group were Dave Maddox, Wendy Cass, Kevin Heffernan, and Paul Geissler (for affiliation and contact information, see Table 1).

This group identified several community types and species that are extremely rare at Shenandoah NP and, therefore, should be part of the inventorying and monitoring program. The priority communities and species identified were:

- Greenstone outcrops
- Mafic fens
- Old Ragtop granite outcrops
- *Phlox buckleyi*
- *Carex polymorpha*
- *Euphorbia purpurea*

In addition, this group stressed that it is important to identify when the community or species is threatened by visitor use and prioritize inventorying and monitoring activities accordingly. For example, resource managers are particularly concerned about populations of rare species and communities that could be negatively affected by visitor trampling. Resource managers are less concerned with rare species and communities that are located "off trail" and therefore tend to be more stable and not as threatened as those in more heavily-visited areas.

Several data collection activities were suggested by this group for inventorying and monitoring rare communities and species. For example, 40 unique or rare communities already have been identified at Shenandoah NP. This group recommended ranking these 40 communities from highest to lowest management priority. In addition, the global and state conservation rankings for the plant species found within each of these 40 communities should be determined. The number of park occurrences for global and state rare plant species should be documented, threats to these species should be identified, and the size of the population for each species should be determined.

<u>Objectives for Special and Unique Ecosystems and Species</u>

This group developed a table that outlines the management and sample objectives for select rare communities or species (Table 2).

Table 2. Unique community or species, threat or issue related to the community or species, management objectives, appropriate management activities, and sampling objective.

Community or Species	Threats/Issue	Management Objective	Management Action	Sampling Objective
Greenstone outcrop	Visitor trampling of 4 plant species.	Use *Potentilla* as indicator. Maintain current density of *Potentilla* within 20%	None	To be 95% confident that we are maintaining a density of *Potentilla* within 20% of current density over the next 5 years.
Mafic Fens	8 species of concern are found in this community type.	Reduce shrub cover 40% in 5 years.	Controlled burning	To be 95% sure of detecting a 40% reduction in shrub coverage over the next 5 years and are willing to accept a 1.5-in-10 chance that we will say a change took place when it really did not.
	Fire sup-pression and overabundance of deer threaten community.	Increase cover of *Carex* by 10% in 5 years	Exclude deer with exclosures	
Phlox	Crash in 1990 levels	Restore 1990 density in 5 years	Controlled burning Mowing	To be 95% confident that we are restoring the 1990 density of *Phlox* within 5 years.
Euphorbia	Overgrowth after gypsy moth infestation	Maintain current denstity within 20%	none	To be 95% confident that *Euphorbia* density is maintained within 20% over 5 years.

The Statistical Evaluation

At the time of this study, Shenandoah NP had more than a decade of vegetation data collected via the LTEMS program. By taking specific objectives developed in the March 2000 workshop and using existing data to obtain measures of statistical variability and magnitude, the ability to estimate parameters with specified precision or detect changes was evaluated.

Statistical Summary of Data, 1987-2000

Estimates of variances and effect sizes (e.g., changes in basal area) are required before statistical power of a given parameter can be estimated. Therefore, the first part of this report presents estimates of basal area and stem density of selected species or groups of species throughout the park, and shrub coverage for selected species at the Big Meadows area. This section is not intended to provide the basis for an evaluation of the LTEMS program to meet specific objectives. The information obtained from this section was used in the next section to develop estimates of statistical power of the current sampling design to detect specified changes in vegetation characteristics at Shenanadoah NP.

Methods

Data analyzed in this report were provided by Shenandoah NP staff from two sources: (1) the LTEMS database for the years 1987-2000 at 104 sampling sites, and (2) the 1998-2000 data collected at the Big Meadows area.

LTEMS data: Ninety-one of the 104 LTEMS sites were randomly selected for a stratified random sampling design developed in 1985, and the additional 13 sites were added as part of subsequent research projects (W. Cass, National Park Service [NPS], personal communication). The strata were eight forest cover types (cove hardwoods, pitch pine, Virginia pine, eastern hemlock, chestnut oak, black locust, northern red oak, and yellow poplar), three elevation ranges (low 381-533 m; mid 686-838 m; and high 991-1143 m), and two aspect ranges (moist 350-100 degrees azimuth; and dry 170-280 degrees azimuth) (W. Cass, NPS, personal communication). In addition, whenever possible, sample plots were located in each of the three park districts (north, central, and south). Table 3 lists the characteristics associated with each sampling site.

At each sampling site a 24 m × 24 m plot was permanently established and diameter at breast height was measured for all woody vegetation >5 m tall within the plot. At three of the corners, 6 m × 6 m plots were established and number of woody stems 1-5 m tall were counted by species. Within each corner plot were two 1 m × 1 m plots where a species-specific count was made of all woody regeneration < 1 m tall.

The areal coverage of each stratum was provided by Shenandoah NP using a Geographic Information System (GIS) in conjunction with a Digital Elevation Model (D. Hurlbert, NPS, personal communication). The original areal coverages used when the sampling design was created were not available. Therefore, because the areal coverages generated from the GIS were not exactly the same ones used as the sampling frame for selecting sample sites, some

Table 3. Characteristics of 104 sampling sites in Shenandoah National Park, 1987-2000, used to evaluate the vegetation monitoring program, which included the forest cover type, aspect (moist 316-135 degrees, dry 136-315 degrees), and elevation (low 381-609 m, mid 610-914 m, high 915-1143 m).

Sampling site	Forest cover type	Aspect	Elevation
1L11	Cove Hardwoods	Dry	High
2L11	Cove Hardwoods	Dry	High
3L10	Cove Hardwoods	Dry	High
1L11	Cove Hardwoods	Dry	Low
1L11	Cove Hardwoods	Dry	Low
3L11	Cove Hardwoods	Dry	Low
1L11	Cove Hardwoods	Dry	Mid
2L11	Cove Hardwoods	Dry	Mid
3L11	Cove Hardwoods	Dry	Mid
2L11	Cove Hardwoods	Moist	High
3L10	Cove Hardwoods	Moist	High
1L11	Cove Hardwoods	Moist	Low
2L11	Cove Hardwoods	Moist	Low
3L11	Cove Hardwoods	Moist	Low
1L10	Cove Hardwoods	Moist	Mid
2L11	Cove Hardwoods	Moist	Mid
3L11	Cove Hardwoods	Moist	Mid
2L12	Pitch Pine	Dry	High
2L12	Pitch Pine	Dry	High
1L12	Pitch Pine	Dry	Low
2L12	Pitch Pine	Dry	Low
3L12	Pitch Pine	Dry	Low
1L12	Pitch Pine	Dry	Mid
2L13	Pitch Pine	Dry	Mid
3L11	Pitch Pine	Dry	Mid
1L12	Pitch Pine	Moist	Low
3L12	Pitch Pine	Moist	Low
3L12	Pitch Pine	Moist	Mid
1L12	Virginia Pine	Dry	Low
3L12	Virginia Pine	Dry	Low
1L12	Virginia Pine	Dry	Mid
1L12	Virginia Pine	Moist	Mid
2L13	Virginia Pine	Moist	Mid
2L12	Eastern Hemlock	Dry	Low
3L11	Eastern Hemlock	Dry	Low
2L13	Eastern Hemlock	Dry	Mid
2L12	Eastern Hemlock	Moist	High

Table 3. Characteristics of 104 sampling sites in Shenandoah National Park, 1987-2000, used to evaluate the vegetation monitoring program, which included the forest cover type, aspect (moist 316-135 degrees, dry 136-315 degrees), and elevation (low 381-609 m, mid 610-914 m, high 915-1143 m). (continued)

Sampling site	Forest cover type	Aspect	Elevation
1L12	Eastern Hemlock	Moist	Low
2L12	Eastern Hemlock	Moist	Mid
2L10	Chestnut Oak	Dry	High
2L30	Chestnut Oak	Dry	High
1L31	Chestnut Oak	Dry	Low
2L10	Chestnut Oak	Dry	Low
1L31	Chestnut Oak	Dry	Mid
2L31	Chestnut Oak	Dry	Mid
1L10	Chestnut Oak	Moist	Low
1L30	Chestnut Oak	Moist	Low
2L10	Chestnut Oak	Moist	Low
2L31	Chestnut Oak	Moist	Low
3L10	Chestnut Oak	Moist	Low
3L10	Chestnut Oak	Moist	Low
1L31	Chestnut Oak	Moist	Mid
2L10	Chestnut Oak	Moist	Mid
2L31	Chestnut Oak	Moist	Mid
3L10	Chestnut Oak	Moist	Mid
2L11	Black Locust	Dry	High
1L11	Black Locust	Dry	Low
1L11	Black Locust	Dry	Mid
2L11	Black Locust	Dry	Mid
3L11	Black Locust	Dry	Mid
3L11	Black Locust	Dry	Mid
2L11	Black Locust	Moist	High
1L11	Black Locust	Moist	Low
2L11	Black Locust	Moist	Low
3L11	Black Locust	Moist	Low
1L11	Black Locust	Moist	Mid
2L11	Black Locust	Moist	Mid
1L10	Northern Red Oak	Dry	High
2L10	Northern Red Oak	Dry	High
2L31	Northern Red Oak	Dry	High
3L10	Northern Red Oak	Dry	High
1L10	Northern Red Oak	Dry	Low
2L10	Northern Red Oak	Dry	Low
3L10	Northern Red Oak	Dry	Low

Table 3. Characteristics of 104 sampling sites in Shenandoah National Park, 1987-2000, used to evaluate the vegetation monitoring program, which included the forest cover type, aspect (moist 316-135 degrees, dry 136-315 degrees), and elevation (low 381-609 m, mid 610-914 m, high 915-1143 m). (continued)

Sampling site	Forest cover type	Aspect	Elevation
1L10	Northern Red Oak	Dry	Mid
1L30	Northern Red Oak	Dry	Mid
2L10	Northern Red Oak	Dry	Mid
3L10	Northern Red Oak	Dry	Mid
1L10	Northern Red Oak	Moist	High
2L31	Northern Red Oak	Moist	High
3L10	Northern Red Oak	Moist	High
1L10	Northern Red Oak	Moist	Low
1L30	Northern Red Oak	Moist	Mid
1L30	Northern Red Oak	Moist	Mid
2L10	Northern Red Oak	Moist	Mid
2L10	Northern Red Oak	Moist	Mid
3L10	Northern Red Oak	Moist	Mid
1L12	Yellow Poplar	Dry	Low
2L12	Yellow Poplar	Dry	Low
2L12	Yellow Poplar	Dry	Mid
3L12	Yellow Poplar	Dry	Mid
1L11	Yellow Poplar	Moist	Low
1L12	Yellow Poplar	Moist	Low
2L12	Yellow Poplar	Moist	Low
3L12	Yellow Poplar	Moist	Low
1L12	Yellow Poplar	Moist	Mid
2L12	Yellow Poplar	Moist	Mid
3L12	Yellow Poplar	Moist	Mid

inconsistencies existed between strata and allocation of sample sites. For example, the GIS provided 27.2 ha in the high elevation yellow poplar stratum, and 46.2 ha of pine stratum at high elevation, but these strata were not defined in the original sampling design, probably because of their small area. These areas were ignored in the analysis because they represent <0.2% of the total area of the park. Aspects of 316-135 degrees azimuth were classified as moist and aspects of 136-315 degrees azimuth were classified as dry. The elevation ranges were 381-609 m (low), 610-914 m (mid), and 915-1143 m (high).

To estimate the population mean, the following formula was used (Cochran 1977:90-91):

$$\hat{\bar{y}} = \frac{1}{N}\sum_{h=1}^{L} N_h \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h}$$

where N_h = number of hectares in stratum h, L = number of strata, y_{hi} = value for plot i in stratum h or the difference between time 1 and time 2 of plot i in stratum h (expressed on a per ha basis), n_h is the number of plots, and

$$N = \sum_{h=1}^{L} N_h .$$

To estimate the population variance of the mean, the following formula was used (Cochran 1977:95):

$$\hat{\mathrm{v}}\mathrm{ar}(\hat{\bar{y}}) = \frac{1}{N^2}\sum_{h=1}^{L} N_h (N_h - n_h)\frac{s_h^2}{n_h}$$

where n_h = number of plots in stratum h and $s^2{}_h$ is defined as

$$s_h^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h} (y_{hi} - \hat{\bar{y}}_h)^2 .$$

Population totals and their associated variances were calculated as

$$\hat{Y} = N\hat{\bar{y}}$$
$$\hat{\text{v}}\text{ar}(\hat{Y}) = N^2 \text{ var}(\hat{\bar{y}}).$$

To calculate confidence intervals (CI) for population means or totals when calculating a difference (e.g., difference in basal area between time 1 and time 2), the following formula was used:

$$\hat{\tau} \pm t_{\alpha/2,df}\sqrt{\hat{\text{v}}\text{ar}(\hat{\tau})}$$

where $\hat{\tau}$ represents the estimate of either the population mean or total, the t-distribution is based on the upper $\alpha/2$ percentile, and the Satterthwaite degrees of freedom (df) are calculated as

$$\textit{Satterthwaite df} = \left(\sum_{h=1}^{L} a_h s_h^2\right)^2 \Bigg/ \left[\sum_{h=1}^{L} (a_h s_h^2)^2 / (n_h - 1)\right]$$

and

$$a_h = N_h(N_h - n_h) / n_h.$$

For estimates of population totals or means, in which the statistic of interest (e.g., basal area, stems/ha, etc.) was $\geq$0, confidence intervals were calculated based on a log-normal distribution using the following formula (Burnham et al. 1987):

$$95\%\ CI = \left[\hat{\tau}/C, \hat{\tau}C\right]$$

where

$$C = \exp\left\{t_{\alpha/2,df}\sqrt{\ln\left(1 + \frac{\hat{\text{v}}\text{ar}(\hat{\tau})}{\hat{\tau}^2}\right)}\right\}.$$

Several problems that arose in analyzing these data need to be explained so that the results can be interpreted correctly. First, all forest cover types were sampled ≥ 2 times during 1987-2000, but not all at the same time (Table 4). Consequently, although changes in tree basal area and stem density for two time periods for each forest cover type could be estimated, inferences across all forest cover types at any given point in time could not be made. Second, in eastern hemlock stands it was not possible to apply the formulas for a random stratified design because most of the strata did not contain >1 sample plot, although most stands were sampled every year. Because of this problem, and that another sampling program was developed specifically to monitor hemlock stands in the park, data from these stands were not analyzed. Third, some strata in black locust and northern red oak forest cover types did not contain >1 sample plot and thus the sampling variance for these strata was not incorporated into the variance estimate for the given forest cover type (Table 4). This means that the variance is underestimated for these cover types. Fourth, the GIS could not separate the various pine stands so pitch pine and Virginia pine were analyzed as if they occurred in a single forest cover type (pine).

For the following tree species, or groups of species, estimates were made of total basal area (m^2) in each forest cover type at each sampling period, and the change in mean (m^2/ha) and total basal area (m^2) between sampling periods: northern red oak (*Quercus rubra*), red maple (*Acer rubrum*), all *Quercus* spp., red oak species (*Q. coccinea, Q. rubra, Q. velutina*), white oak species (*Q. alba, Q. bicolor, Q. prinus*), yellow poplar (*Liriodendron tulipifera*), pitch pine (*Pinus rigida*) and Virginia pine (*Pinus virginiana*), black locust (*Robinia pseudoacacia*), and black birch (*Betula lenta*).

Estimates were made of stem density (stems/ha) for shrubs and saplings (1-5 m tall) in each forest cover type, and changes in mean stem density for each of the following species and groups of species: mountain laurel (*Kalmia latifolia*), sassafras (*Sassafras albidum*), brambles (*Rubus* spp.), spicebush (*Lindera benzoin*), flowering dogwood (*Cornus florida*), ash spp. (*Fraxinus* spp.), red maple, and bear oak (*Q. ilicifolia*).

Estimates also were made of stem density (stems/ha) for woody vegetation <1 m tall (seedlings) in each forest cover type and changes in mean stem density for the following species and species groups: blueberry (*Vaccinium* spp.), white oak species, red maple, all oak species, northern red oak, flowering dogwood, yellow poplar, ash species, mountain laurel, brambles, and birch spp. (*Betula* spp.).

Big Meadows Data: Data of shrub coverage in Big Meadows were provided for three areas of the meadow (central, north, and south) for plants >0.5 m tall. The central area contained wetland habitat and was 6.17 ha, the north area was 17.1 ha, and the south area was 16.0 ha. Sixty-three randomly oriented 50-m transects were randomly located in the three areas in proportion to the size of each area (central - 10 transects, north - 27 transects, south - 26 transects). Areal coverage of shrubs was estimated using the line intercept method (W. Cass, NPS, personal communication).

Table 4. Summary of characteristics (area, number of plots [*n*], and years when sampled) of strata (forest cover type, elevation, and aspect) in Shenandoah National Park, 1987 – 2000.

Forest cover type	Elevation	Aspect	Area (ha)	*n*	Period (years) sampled	
					First	Second
Cove Hardwoods	High	Dry	823.6	3	1988-89	1993-94
		Moist	963.0	2	1988	1993-94
	Medium	Dry	2,716.8	3	1988-89	1993-94
		Moist	4,009.0	3	1988-89	1993-94
	Low	Dry	1,394.8	3	1988-89	1993-94
		Moist	1,702.4	3	1988-89	1993-94
Pine	High	Dry	34.5	2	1990-91	1999
		Moist	46.1	0		
	Medium	Dry	1,139.8	4	1990-91	1999
		Moist	518.3	3	1991	1999
	Low	Dry	1,799.0	5	1990-91	1999
		Moist	796.7	2	1991	1999
Chestnut Oak	High	Dry	1,062.2	2	1987-88	1992-94
		Moist	614.9	2	1988	1991-93
	Medium	Dry	11,324.2	2	1987	1992
		Moist	9,383.1	4	1987-88	1992-94
	Low	Dry	8,302.8	2	1987-88	1992-93
		Moist	7,286.8	6	1987-88	1992-94
Black Locust	High	Dry	381.8	1	1989	1994
		Moist	396.7	1	1989	1994
	Medium	Dry	830.4	4	1989	1994
		Moist	821.7	3	1989-90	1994
	Low	Dry	333.9	1	1989	1994
		Moist	433.6	3	1989	1994
Northern Red Oak	High	Dry	1,702.8	5	1988	1992-93
		Moist	1,874.4	3	1987-88	1992-93
	Medium	Dry	1,217.2	4	1987-88	1992-93
		Moist	1,528.8	5	1987-88	1993
	Low	Dry	558.9	3	1988	1992-94
		Moist	501.9	1	1988	1993

Table 4. Summary of characteristics (area, number of plots [*n*], and years when sampled) of strata (forest cover type, elevation, and aspect) in Shenandoah National Park, 1987 – 2000. (continued)

					Period (years) sampled	
Forest cover type	Elevation	Aspect	Area (ha)	*n*	First	Second
Yellow Poplar	High	Dry	9.1	0		
		Moist	18.1	0		
	Medium	Dry	2,024.6	3	1991	2000
		Moist	2,200.0	3	1991	2000
	Low	Dry	3,225.5	3	1991	2000
		Moist	4,598.6	4	1990-91	2000
Hemlock[a]	High	Dry	34.5	0	1990	2000
		Moist	98.9	1	1990	2000
	Medium	Dry	77.2	1	1990	2000
		Moist	139.5	1	1990	2000
	Low	Dry	86.0	2	1990	2000
		Moist	102.3	1	1990	2000
Total			77,114.5	104		

[a] Hemlock forest cover type was surveyed every year during 1990-2000, except 1991 and 1999.

Areal coverage was estimated for the following species: panicled dogwood (*Cornus racemosa*), hazelnut (*Corylus americana* and *C. cornuta*), hawthorn (*Crataegus* spp.), black huckleberry (*Gaylussacia baccata*), maleberry (*Lyonia ligustrina*), black locust (*Robinia pseudoacacia*), brambles (*Rubus* spp.), broadleaf meadowsweet (*Spirea latifolia*), upland low blueberry (*Vaccinium pallidum*), squaw huckleberry (*Vaccinium stamineum*), and all shrub species combined. Meadow-wide estimates were calculated using the same stratified estimators described for the LTEMS data. Some species only occurred in the central wetland area (panicled dogwood, hazelnut, and broadleaf meadowsweet), or the upland (north and south) meadow area (black locust), and thus areal coverage estimates for those species only were calculated for the areas in which they occurred.

Data from 1998 and 1999 were pooled because the 63 transects were sampled once over the two years and these years were prior to the treatment of burning. All 63 sites were sampled in 2000, and were considered post-treatment data. In addition to estimating areal coverage for each species pre- and post-treatment, a paired difference in areal coverage pre- and post-treatment was calculated. Eighty-five percent confidence intervals for coverage estimates were calculated.

Results

Tree Basal Area: The coefficient of variation (CV = standard error/mean × 100%) of estimated for trees (>5 m tall) in plots paired over time were highly variable, and ranged from 15-548% among species in all forest cover types. Poor precision was expected for some situations (e.g., oak species in pine stands), and CVs were generally <40% for species in vegetation types where they were most abundant (e.g., northern red oak in chestnut oak and northern red oak cover types). Results were similar for the precision of estimates of basal area at each sampling period.

Overall, the monitoring program detected >2 m^2/ha declines (upper limit of 80% CI [confidence interval] was <0) in the basal area of oaks and pines in certain vegetation types (see Appendix, Tables A and B). Increases were detected in basal area (lower limit of 80% CI was >0) of yellow poplar in yellow poplar and black locust cover types, as well as in basal area of red maple in the northern red oak cover type.

Shrub and Sapling Stem Density: Few changes in stem density were detected for shrubs and saplings (vegetation 1-5 m tall). Most CVs were >50% (range 31-1,169) and 80% CIs were wide and most encompassed zero (Appendix C). For example, *Rubus* spp. showed large increases in stem density, but none of the changes were statistically significant. Appendix D provides a summary of estimates of abundance (stems/ha), CVs, and 80% CIs for the first and second sampling periods for each forest cover type.

Seedling Stem Density: The results for seedlings (<1 m tall) were similar to those obtained for shrubs and saplings (Appendix, Tables E and F). Few changes were statistically different from zero, except when extreme changes occurred. For example, there was a decline in oak seedlings in chestnut oak stands; however, the precision of this estimate was poor (mean change = -7,114.7 stems/ha, 80% CI = -11,892 – 2,338).

Forest Health:
Flowering dogwood – All of the forest cover types, except cove hardwoods, exhibited declines in shrub stem density for flowering dogwood, and the declines were significant in pine, black locust, and yellow poplar forest cover types (Appendix C). The CVs ranged from 31 to 61%. In contrast, the stem density of flowering dogwood seedlings was highly variable; the mean change ranged from -3,845.7 stems/ha to 1,589.3 stems/ha. In chestnut oak and black locust forest cover types the change was positive (Appendix E). The CVs ranged from 5 to 117%.

Tree-of-heaven – All forest cover types, except pine, exhibited an increase in sapling stem density for tree-of-heaven (mean change of 3.8-143.0 stems/ha), but none of these changes were statistically different from zero except in the yellow poplar cover type (CVs ranged from 64-80%; Appendix, Tables G and H). Results were similar for changes in stem density of seedlings in which CVs ranged from 69-4,372%.

Gypsy moth – The effects of gypsy moths should be most evident in the decline in basal area for oak species in chestnut oak and northern red oak forest cover types. In general, CVs for oaks in these cover types were <40% and declines were detected for northern red oak and red oak species. White oaks did not exhibit a decline in the chestnut oak cover type, but did decline in the northern red oak cover type (Appendix, Tables A and B). Percent declines in basal area were 28-40% for oak species or oak species groups, except white oaks, in both forest cover types.

Big Meadows Shrub Cover: The coverage of tall shrubs in Big Meadows was quite low with percent cover generally <2% for most species (Appendix I). Only panicled dogwood (16.2%) and broadleaf meadowsweet (18.5%) had mean coverage values >10% prior to burning. Consequently, CVs of percent cover estimates were high (>50%), even for estimated declines in percent cover based on paired-difference estimates (Appendix J). Estimates for all shrub species combined, however, were reasonably precise for both estimates pre- and post-treatment and paired-transect differences (CVs < 18%).

In the wetland area, tall shrub coverage declined from 41.59% (SE = 11.2) to 7.28% (SE = 3.7) for a decline of 34.31% (85% CI = 19.7-48.9). In the upland area, tall shrub coverage declined from 32.23% (SE = 4.62) to 10.48% (SE = 1.59) for a decline of 21.74% (85% CI = 16.0-27.5).

Estimates of Statistical Power to Meet Objectives

Estimating statistical power to detect changes in basal area, stem density, or percent cover can be used to assess whether current sampling efforts can meet stated objectives. Here, estimates of means and variances obtained from the statistical summary were used to estimate the statistical power to detect a range of changes in basal area, stem density, and percent cover for specific sample sizes. Statistical power was estimated for the following objectives:

1. Data collected for the LTEMS program should ensure a 90% probability of detecting a $\geq$50% change in the basal area or stem density of any wood plant species (in a given size class) within any one forest cover type over a five-year period ($\alpha = 0.20$). The ability of current sampling efforts to meet this objective was assessed by calculating power curves for tree basal area, shrub and sapling stem density, and seedling stem density.
2. Data collected for the LTEMS program should ensure an 80% probability of detecting a $\geq$20% change in the coverage of a particular exotic species parkwide over a five-year period ($\alpha = 0.20$). The ability of the current LTEMS program at SNP to meet this objective was assessed using the power curves calculated above for changes in sapling and seedling stem density of tree-of-heaven. Stem density was used as an indicator of aerial coverage for this species.
3. Data collected for the LTEMS program should ensure an 80% probability of detecting a $\geq$20% change parkwide in species affected by disease or insects over a five-year period ($\alpha = 0.20$). The ability of the current LTEMS program at Shenandoah NP to meet this objective was assessed using the power curves calculated above for changes in shrub and seedling stem density of flowering dogwood and tree basal area of all oak species.
4. Monitoring of shrub coverage at Big Meadows should ensure a 95% probability of detecting a $\geq$40% reduction in shrub coverage over a five-year period ($\alpha = 0.15$). The program TRENDS was used to estimate the statistical power to detect these changes.

Estimating sample sizes in a stratified sampling design is difficult if the size of strata and variances differ, which is why Satterthwaite df, which weights the variances of each stratum by its size (ha), was used. If all strata are the same size, and variances and sample sizes are equal, the Satterthwaite df reduces to *n*-*L*, where *n* is the number of sampling plots and *L* is the number of strata. As an example, if all strata were the same size in the northern red oak forest cover type (21 plots, Appendix A), of which there were 6 strata (3 elevation x 2 moisture), the degrees of freedom would have been 15. However, hectares among these strata ranged from 501.9-1,702.8 and the moist aspect-low elevation stratum contained only 1 plot, which does not permit the estimation of variance for that stratum. Consequently, for this example, the Satterthwaite df was only 10 for basal area of red maple in this cover type.

Regardless of the variability in sample sizes for various species and forest cover types, when using the power curves created in this report to make inferences about sample sizes required, the following relationship is a useful starting point for estimating sample size requirements:

$$n = 4 \times \mathit{Satterthwaite\ df}\,.$$

This is based on the fact that the average Satterthwaite df $\cong$ 4 (for basal area and stem densities in the Statistical Summary of Data section of this report) and the average number of plots per forest cover type was 16.

Methods

Statistical power to detect changes (mean difference of paired plots between sampling periods via a *t*-test) was estimated in tree basal area, shrub and sapling stem density, and stem density of seedlings. Because the variance of these parameters was positively correlated with the mean, the standard deviation (SD) was first modeled as a linear function of the mean change. From the statistical summary, standard errors, and Satterthwaite df for individual species in all forest cover types were obtained, and these were used to construct a linear model. From this model the standard deviation could be predicted for a given absolute value of the change in the parameter of interest. For changes in basal area or stem density beyond the limits of the linear model, the estimate of standard deviation from the largest change in basal area or stem density in the model was used.

It was assumed that the distribution of mean change (mean of paired-plot differences) in the parameter of interest (θ; i.e., basal area or stem density) could be described by a *t* distribution, in which the SE(θ) was a function of the mean and sample size. Figure 1 is an example of the SAS program used to calculate the power of detecting a given difference in θ and Satterthwaite df. In the simulations, $\alpha = 0.20$, Satterthwaite df ranged from 2 to 10, basal area ranged from 0 to 9 m^2/ha, shrub/sapling stem density ranged from 0 to 5,000 stems/ha, and seedling stem density ranged from 0 to 70,000 stems/ha.

Program TRENDS (Gerrodette 1993) provides estimates of statistical power to detect changes in a trend. This program was used to estimate the power to detect an exponential decline in shrub coverage at the rate of 9.8% per year (40% in 5 years). For inputs into Program TRENDS, CV = 13%, 20%, and 25%, $\alpha = 0.15$, 1-tailed *t*-test, exponential decline in shrub coverage were used, and CV was directly proportional to shrub coverage. Power was estimated for 3-10 years of sampling.

Results

The average Satterthwaite df = 4 for estimates of tree basal area and shrub, sapling, and seedling stem density within each forest cover type was presented in the statistical summary of this report. Thus, the graphs of estimated statistical power for changes in basal area and stem density at Satterthwaite df = 4 provide a measure of the statistical power of the current sampling effort for the LTEMS at Shenandoah NP.

It was possible to model standard deviation as a function of mean change in basal area and stem densities. The relationship between the mean change in tree basal area (BA) and standard deviation (SD) was described by the equation SD = 0.11368 + 0.89710 * BA ($F_{1,33} = 238.9$, $P < 0.001$, $R^2 = 0.88$). The relationship between the mean change in shrub and sapling stem density (STEM) and standard deviation was described by the equation SD = 83.03489 + 0.72778 * STEM ($F_{1,27} = 72.7$, $P < 0.001$, $R^2 = 0.73$). The relationship between the mean change in seedling stem density (REGEN) and standard deviation was described by the equation SD = 868.83149 + 1.01217 * REGEN ($F_{1,41} = 106.8$, $P < 0.001$, $R^2 = 0.72$). Figure 2 provides scatterplots of the data along with the fitted regression line, which show that heteroscedasticity (non-constant variances) needs to be incorporated in analyses of power.

```
************************************************
*
*        This SAS program estimates statistical power
*                  to detect changes in basal area (BA)
*
*
*        Written by Duane R. Diefenbach, July 2001
************************************************;

data power;

 do df = 2 to 10 ;                 * Satterthwaite degrees of freedom;
     do diff = 0 to 9 by 1;        * Change in basal area (m^2/ha);
       sd0 = .11368;                      * Std Dev of estimate of no change in BA;
       sd = .11368+.89710*diff;          * Std Dev for given mean change in BA;
       if diff>4 then sd = .11368+.8971*4;      * Std Dev beyond the regression model;
     se = sd/sqrt(df); se0 = sd0/sqrt(df);        * Std Errors;
     cv = int(se/diff*100);

     nullhigh = tinv(.9,df); nulllow = tinv(.1,df); *t-statistics for null dist;
     low = nulllow+diff/se; high = nullhigh+diff/se;*t-stats for the change;
        powerlow = probt(low,df); powerhigh = 1-probt(high,df);
        power = int((powerlow+powerhigh)*1000)/10; *Power or 1-Beta;
        output;
 end;  end;

proc sort; by diff df;
proc print;
 title 'Power to Detect Changes in BA';
 var diff df se0 se power;
proc plot;
  plot power*df = diff;
  quit;
run;
```

Figure 1. SAS program used to estimate statistical power for basal area. Power analyses for stem density simply used different coefficients to estimate variables SD0 and SD, as well as different ranges for variable DIFF.

A)

B)

C)

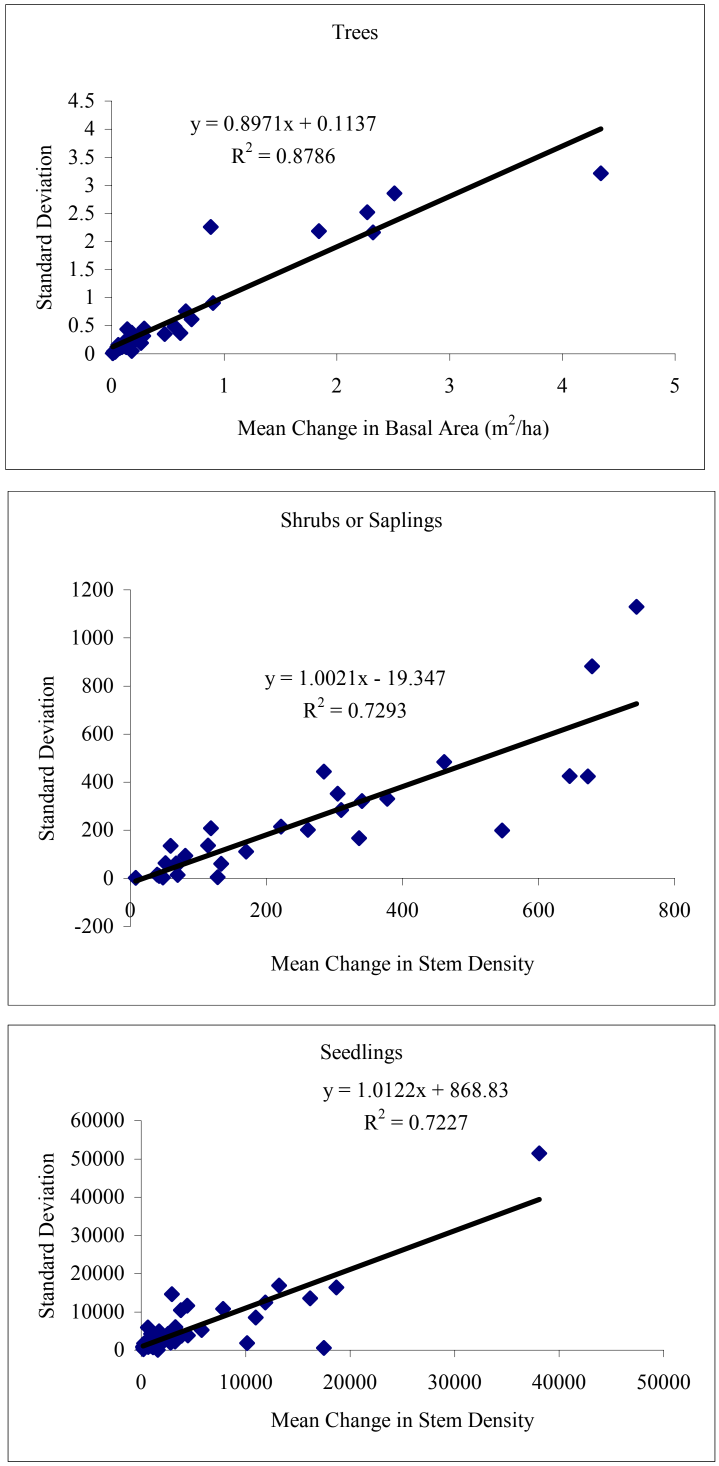

Figure 2. Scatterplot with regression line for the relationship between standard deviation and mean changes in (A) basal area of trees (m^2/ha), (B) stem density of shrubs or saplings (stems/ha), and (C) stem density of seedlings (stems/ha).

Tree basal area: The estimates of statistical power indicated that current sample sizes (4 Satterthwaite df) would permit detection of a change of 6 m^2/ha with 90% power, which represents a 10% change at 60 m^2/ha, 20% change at 30 m^2/ha, and 50% at 12 m^2/ha. Figure 3 presents the estimates of power for increasing sample sizes and changes in basal area. Because most basal area measurements are >20 m^2/ha for species in their primary forest cover types (e.g., yellow poplar in cove hardwoods, northern red oak in chestnut oak cover type, etc.), current sampling effort should have $\geq$90% power to detect changes in basal area of 50% for dominant species.

Shrub and sapling stem densities: Under current sampling effort (mean Satterthwaite df = 4), statistical power was estimated $\geq$90% for changes in stem density of ~2,000 stems/ha or greater. However, the ability to detect smaller changes with 90% power will probably require a doubling of sampling effort. Only 6 of 74 estimates of stem density were >1,000 stems/ha (Appendix D), which indicates that current sampling effort has low power to detect even 50% changes in stem density. Figure 4 presents the estimates of power for increasing sample sizes and changes in shrub stem density.

Seedling stem density: Only large changes (>70,000 stems/ha) in seedling stem density are likely detectable under the current sampling effort. Few species have seedling stem densities that exceed 10,000 stems/ha, and most are <3,000 stems/ha (Appendix F). Tripling the current sampling effort is still unlikely to provide sufficient power to detect large changes in stem densities for most species. Figure 5 presents the estimates of power for increasing sample sizes and changes in seedling stem density.

Tree-of-heaven: Increases in stem density for tree-of-heaven >1m tall (sapling) ranged from 0-143 stems/ha (Appendix G). The ability to detect such changes is poor (power < 70%) even if sample sizes were tripled. Average stem density was low for tree-of-heaven in the sapling class (0-165 stems/ha, Appendix H) such that the power to detect even 100% increases would be quite poor even with substantial increases in sample size (Figure 4).

Changes in stem density for tree-of-heaven seedlings was highly variable and ranged from -3,368.2 to 206.7 stems/ha (Appendix G). Stem density ranged from 0 to 5,298.0 stems/ha (Appendix H). Regardless, these densities and changes would have a poor chance of being detected under current sampling efforts. Sample sizes would have to be ~4 times greater to detect a change of 5,000 stems/ha, which represents a >100% increase from some of the greatest stem densities that presently exist at Shenandoah NP.

Flowering Dogwood: Shrub stem densities for flowering dogwood ranged from 15.7 to 536.1 stems/ha (Appendix D). Under current sampling efforts, power is >80% for changes >1,000 stems/ha. Consequently, the sampling effort would have to increase 2-3 times current levels to detect ~100% changes in current densities. Seedling stem densities were variable, but declined as much as 3,800 stems/ha between sampling periods (Appendix E). Regardless, power to detect even large changes in seedling stem density will be nearly impossible without unrealistically large increases in sample size.

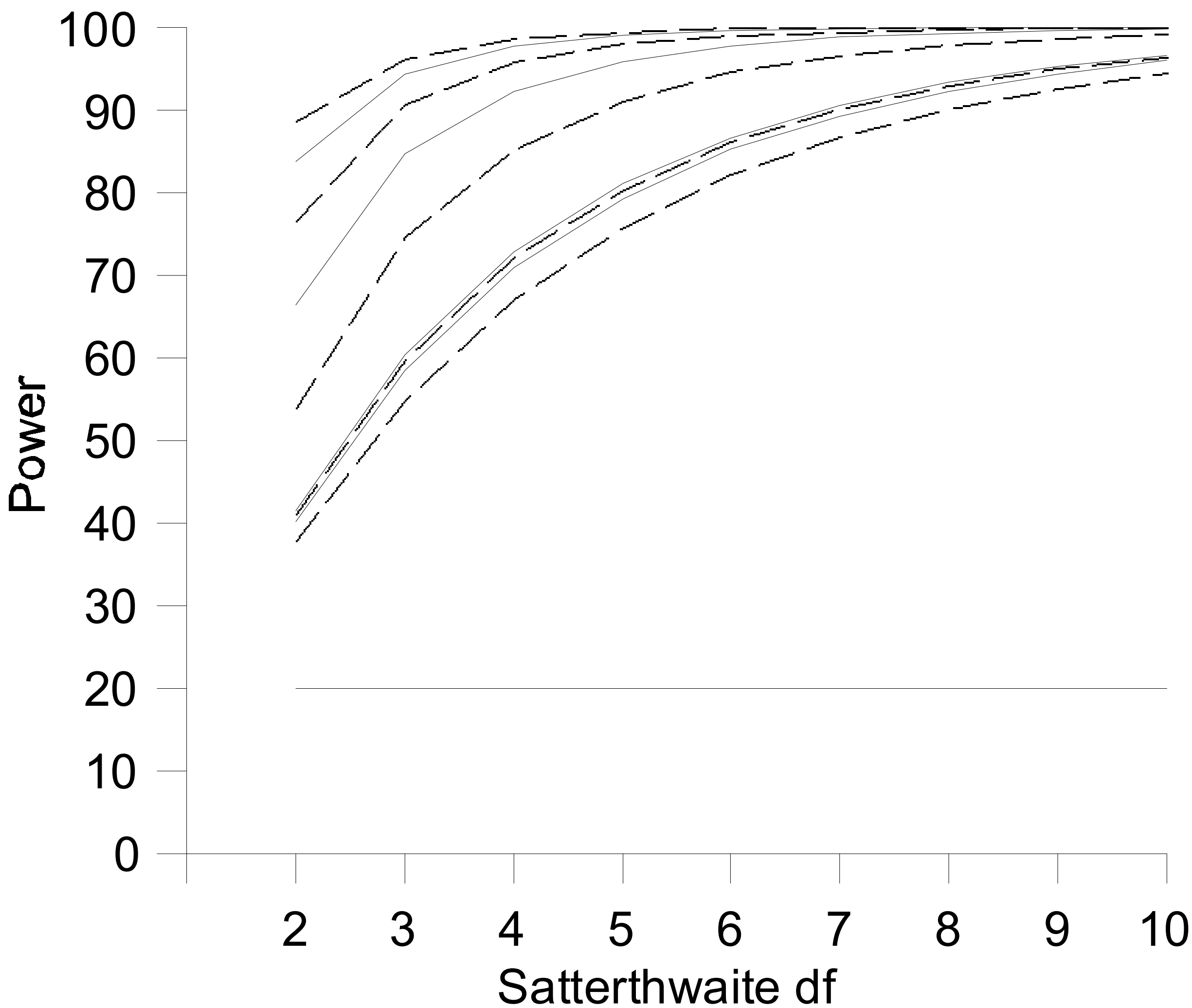

Figure 3. Estimated power to detect a change in tree basal area (m^2/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in basal area of 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 m^2/ha.

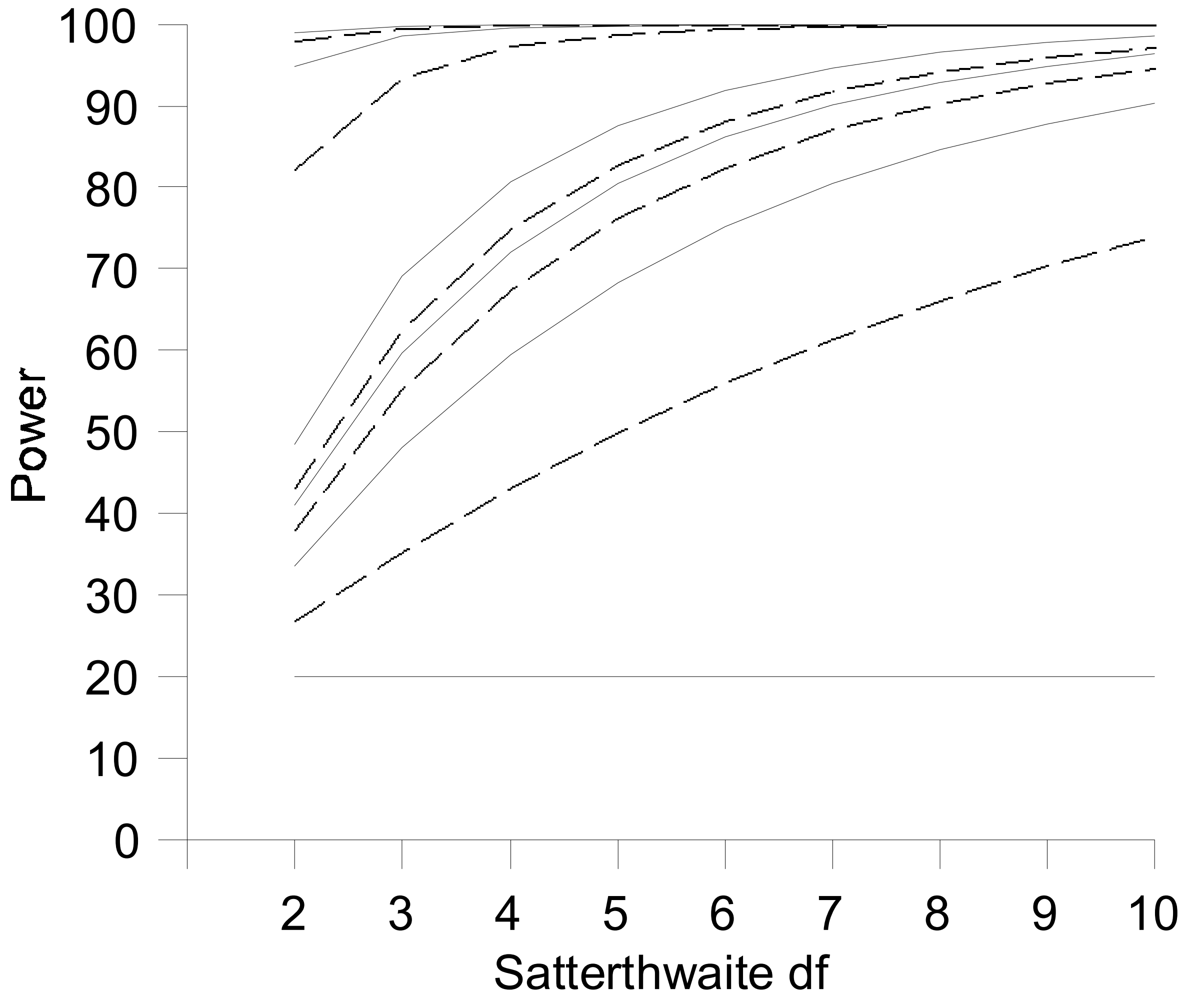

Figure 4. Estimated power to detect a change in shrub or sapling stem density (stems/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in stem density of 0, 100, 200, 300, 400, 500, 1,000, 2,000, 3,000, 4,000, and 5,000 stems/ha.

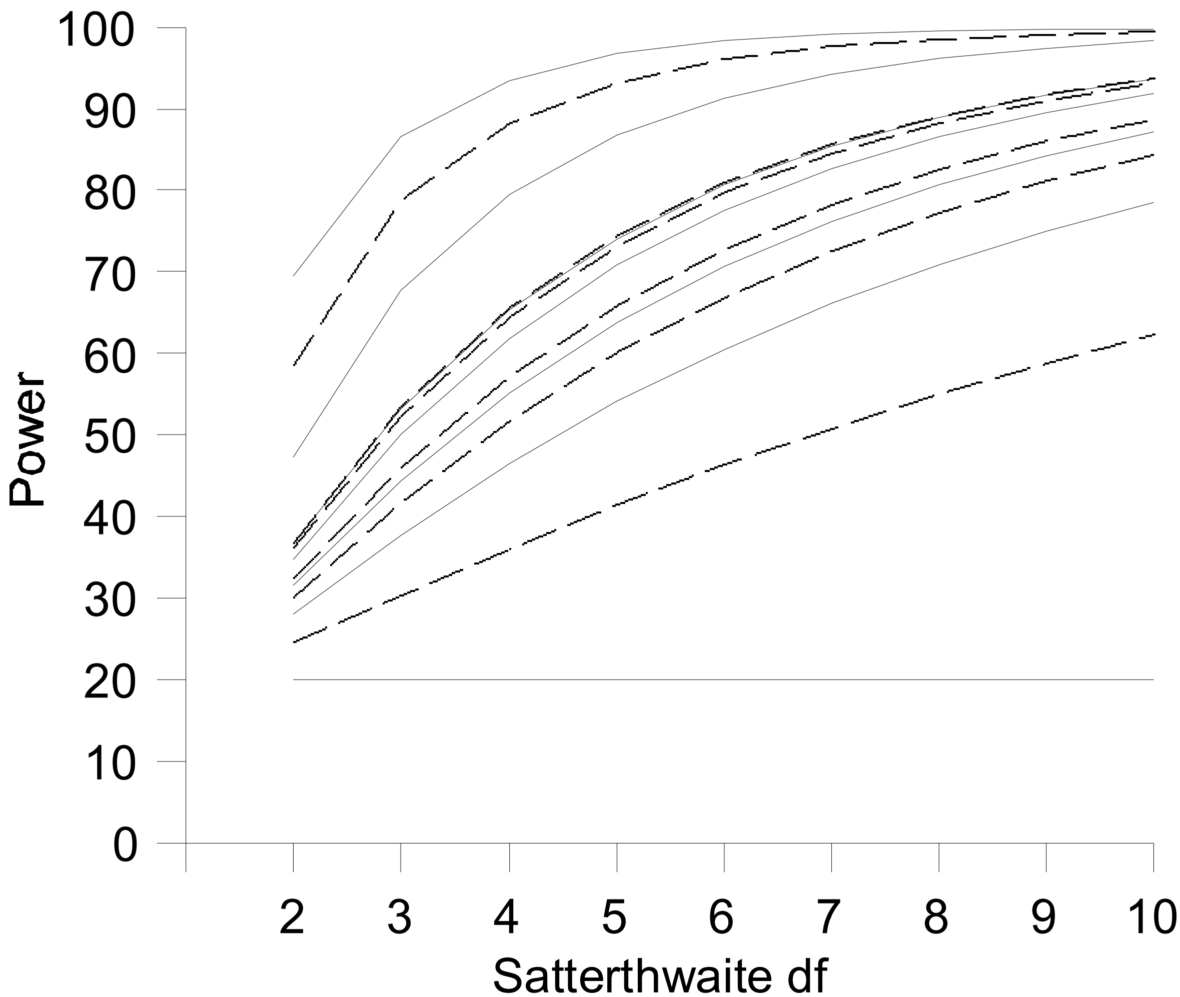

Figure 5. Estimated power to detect a change in seedling stem density (stems/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in stem density of 0, 1,000, 2,000, 3,000, 4,000, 5,000, 10,000, 20,000, 30,000, 40,000, 50,000, 60,000, and 70,000 stems/ha.

Gypsy moth: The effect of gypsy moth on oak abundance, as measured by changes in basal area for all oak species, has a good chance of being detected under current sample sizes. For example, between sampling periods, oak basal area declined from 29.2 to 26.0 m^2/ha in chestnut oak cover type, and declined from 23.9 to 17.5 m^2/ha in northern red oak cover type. These changes represented a mean change (using paired plots) of -3.2 and -6.4 m^2/ha, respectively (Appendix A). According to Figure 3, the statistical power to detect this magnitude of decline is >70% and >90%, respectively. Mean stem densities of oak saplings ranged from 0 to 871 stems/ha, and thus the ability to detect only large changes in stem densities (>1,000 stems/ha) for saplings will likely have acceptable power (Figure 4).

Shrub cover at Big Meadows: The present sampling design should have a good chance (power ~95%) to detect desired changes in overall shrub coverage, assuming a declining trend exists. For example, for CV = 13% and a sampling period of five years, statistical power is estimated to be 93% (Figure 6).

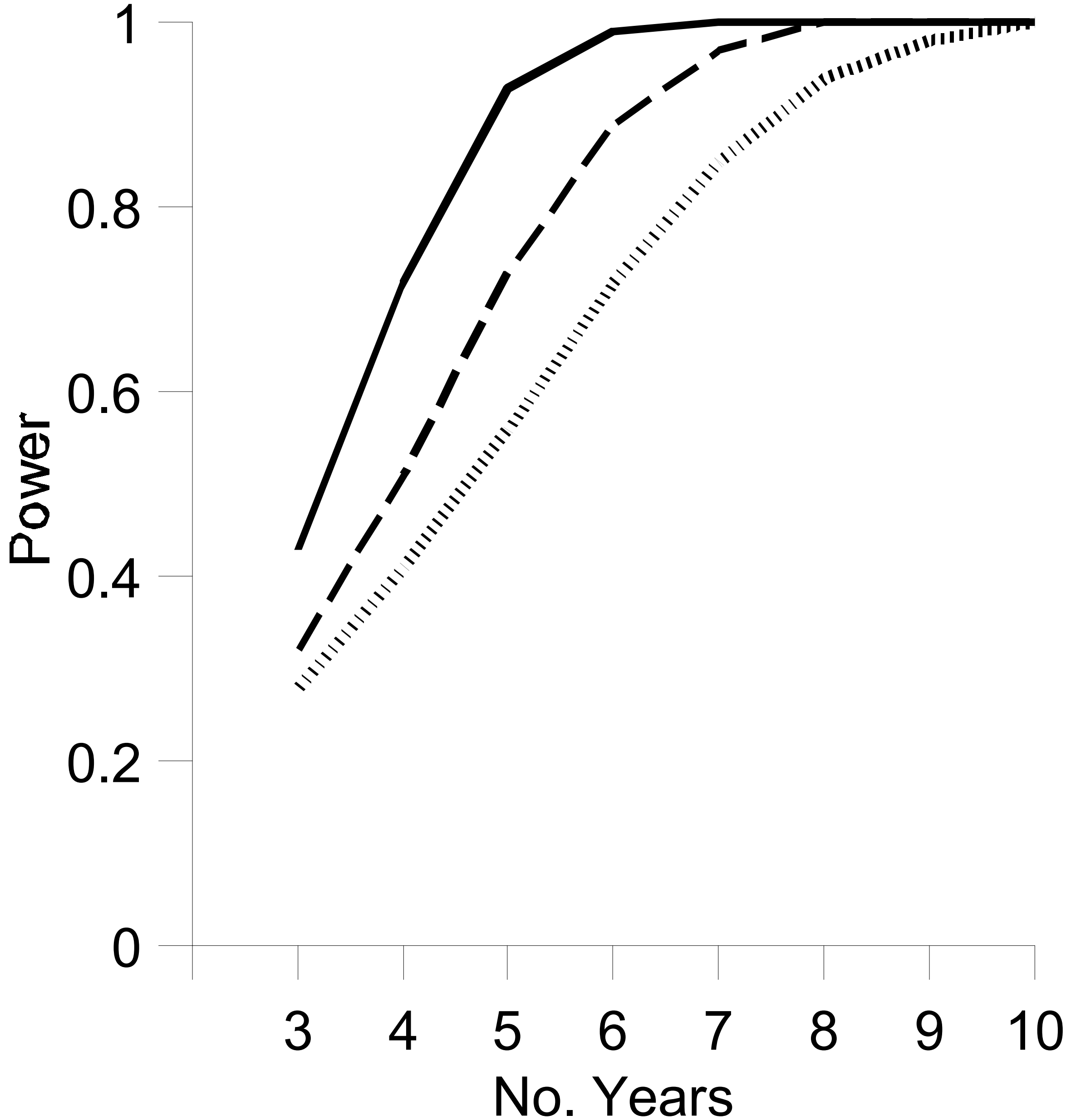

Figure 6. Estimated power to detect a 9.8% decline per year (40% over 5 years) in percent shrub coverage in Big Meadows, Shenandoah National Park for CV = 13% (solid line), 20% (dashed line), and 25% (dotted line) over 3-10 years (= 0.15, 1-tailed t-test, exponential decline in shrub coverage).

Discussion and Recommendations

Recommendations to improve the sampling design of the LTEMS at Shenandoah NP arise from investigation of the current sampling design, issues related to data collection, and results of the power analysis. Several issues related to current sampling design and data collection are compromising the ability of the LTEMS to detect or monitor changes in vegetation composition and characteristics. Also, the power analyses indicate that precision of estimates of shrub, sapling, and seedling stem densities are not sufficient to detect biologically important changes, although precision seems adequate for monitoring basal area for most tree species throughout the park and shrub coverage in Big Meadows.

Sampling Design

The stratified sampling design is a good approach to increasing precision of estimates, and the strata of moisture, elevation, and forest cover types seem to be appropriate to identify areas with similar vegetative characteristics (however, see Conclusions section). There are three problems with the current selection and visitation of sample plots.

First, the sample selection is technically flawed because not all areas of the park had a probability of selection >0. This is because the elevation and moisture strata were defined as disjunct intervals with the intention of ensuring that plots from different strata were not physically near one another. Although technically incorrect, this is probably not a serious flaw in the sampling scheme. If additional plots are added to the LTEMS, these disjunct intervals should be eliminated. One means of ensuring an even spatial distribution of plots might be to subdivide strata into equal-sized areas and then randomly select plots from within these substrata with equal probability. These plots among substrata could then be combined into a single strata as if they were never sub-stratified.

Second, some strata contain only a single sample plot. This is such a problem within the hemlock sites that stratified random sample estimators cannot be used if estimates of variance are to be obtained. Other estimators have been proposed in which there is only one unit per stratum (Cochran 1977:138-140), but they either require knowledge of covariates that correlate strongly with the variable of interest, or *a priori* knowledge of how pairs of plots in different strata should be combined. This approach is not recommended because it can lead to variance estimates biased low, and it would probably be difficult to identify appropriate pairs of plots among different strata.

Most strata contain only two plots because there is such a large number of strata (42). Therefore, it is strongly recommended to increase sample sizes to ensure >1 plot, and preferably >2 plots, per stratum for improved precision. Nearly all forest cover types have Satterthwaite df < 10 and the majority are <5, which results in wide confidence intervals. Under the current sampling design, sample sizes would have to be doubled to detect changes in stem density of shrubs and saplings specified for LTEMS objectives.

Third, the sampling effort is not consistent among forest cover types because of limited personnel resources. Over the period 1988-2000, Shenandoah NP personnel attempted to visit all plots within a forest cover type during a given field season; for example, all plots in the chestnut oak cover type were surveyed one year, and all plots in cove hardwoods were surveyed the following year. This type of data collection protocol permits estimates of changes in vegetation between two time periods (within a given forest cover type), but it does not permit an estimate of a given parameter (e.g., basal area of northern red oak) for a given year across all forest cover types. Consequently, estimates of changes over time of chestnut oak basal area in the chestnut oak cover type are temporally distinct from the changes estimated for chestnut oak basal area in the northern red oak cover type. This problem greatly limits the ability of LTEMS to monitor changes in vegetation.

The problems associated with sample size and the order in which plots are visited are the two most serious problems with the LTEMS at Shenandoah NP. Sample sizes are limiting the ability of the LTEMS program to provide precise estimates of vegetation parameters (i.e., CV < 25%). The timing of when sample plots are visited is compromising the ability of the program to detect changes over time because differences among forest cover types are confounded by year of sampling.

It is strongly recommended that the park investigate an alternative sampling design in which some plots are visited annually (or within some multi-year period) and other plots are visited on a systematic basis. This type of sampling design is described in Urquhart *et al*. (1998) along with the benefits for obtaining point estimates as well as trends over time.

Data Collection

Correct species identification is known to be a problem for similar species (e.g., scarlet oak and red oak; W. Cass, personal communication). These types of errors create difficulties in assessing whether the changes detected in basal area or stem density were caused by recording errors, environmental perturbations, or simply reflect differences in life-history characteristics. For example, scarlet oaks have shorter life spans than red oaks, and if scarlet oaks are incorrectly identified the data may suggest declines in red oak when in fact it simply represents natural mortality in scarlet oaks. The other type of data collection error that was encountered was missing data. For example, in one plot in the pine forest cover type only the dbh of pine trees was entered into the database.

The types of errors outlined above are unavoidable, but can be minimized. Misidentification errors can be reduced by hiring skilled technicians. More importantly, however, the present effort to permanently mark trees with unique identifiers within each permanent plot (W. Cass, personal communication) will greatly reduce misidentification errors. Finally, fully implementing a field-based data-entry system (*sensu* Krueger and Rich 2001) can greatly reduce errors by prompting technicians to document the status of trees measured in previous years, checking for data-entry errors, and eliminating transcription errors from paper datasheets.

Power Analysis

The estimates of power presented in this report are based on estimates of variances obtained in the statistical summary, changes in basal area and stem density deemed reasonable (i.e., expected to occur), and assumptions about the distribution of those changes. Specifically, it is assumed the estimated change followed a *t* distribution and that variance was positively correlated with the mean. Consequently, the estimates of power presented in this report contain some unknown bias and precision; however, bias is likely low although precision may be poor (Gerard *et al*. 1998:805).

Power analyses cannot be used to interpret results, and thus applying power curves generated in this report to assess specific results presented in the previous section is not recommended to determine the "statistical power" of an estimate of change (see Gerard *et al.* 1998). Once data have been collected and estimates calculated, confidence intervals should be used to assess whether changes have occurred (e.g., whether the CI encompasses zero) and CVs, or the lengths of confidence intervals, should be used to assess the precision of estimates.

The value of the power analysis presented in this report is to provide guidance on the ability of the current sampling design to detect specified changes in basal area or stem density. Moreover, alternative study designs can be evaluated with respect to specific objectives and to some extent the benefit of design changes (primarily increased sample size) can be estimated.

The number of sample plots needs to be increased for two reasons: (1) some strata do not contain >1 sample plot, and (2) power curves suggest that only relatively large changes in shrub or sapling stem density have a reasonable chance of being detected. Changes in basal area of >5 m^2/ha have >90% chance of being detected under the current sampling design at Shenandoah NP. However, only changes >2,000 stems/ha have a >90% chance of being detected for shrubs or saplings (i.e., vegetation 1-5 m tall). Most stem densities of shrubs and saplings are <1,000, which requires sample sizes that would permit changes of 400-500 stems/ha to be detected with power >80%.

It is probably not reasonable to expect to be able to detect even large changes in seedling stem density (i.e., vegetation <1 m tall). The power curves suggest that doubling current sample sizes still would only provide sufficient power to detect changes of >20,000 stems/ha. It is likely that the inherent spatial variability in abundance of seedlings will make meeting any reasonable objective costly and logistically impossible.

The power analysis to detect a trend in shrub coverage is likely a conservative estimate, however, and may not be the best measure of detecting changes. Because shrub coverage is being controlled in Big Meadows via mowing and/or burning, it is reasonable to believe that shrub coverage has in fact declined (similar to the situation in which logging reduces basal area), and a more important question is whether estimated changes in shrub coverage will have adequate precision to detect biologically important changes. Given that the estimates of paired differences and absolute amounts of shrub coverage pre- and post-treatment had CVs < 20%, biologically important changes in shrub coverage will most likely be detectable under the current sampling design. However, obtaining precise estimates of changes in shrub coverage for individual species probably will be possible only for the most abundant species.

Conclusions

The most important change recommended for the LTEMS program at Shenandoah NP would be to implement a sampling design that will permit regular estimates of park-wide parameters (e.g., an estimate of basal area), yet also permit estimates of trends over time (*sensu* Urquhart *et al*. 1998). This type of sampling design would greatly improve the inferences that can be obtained from LTEMS regarding changes in the vegetative communities in the park.

However, before such a design is implemented, there are spatial issues regarding monitoring changes in the vegetation in Shenandoah NP which must be considered. Traditional sampling theory (e.g., Cochran 1977) does not explicitly consider spatial configuration of sampled units in the sampling design. For example, stratified sampling is based on an assumption that the strata do not change, which may not be a good assumption for vegetation types that may be changing over time (e.g., pine vegetation types being replaced by hardwoods). Consideration should be given as to how the spatial distribution of vegetation types will be estimated before any changes to the sampling design of the monitoring program are implemented.

Literature Cited

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5, Bethesda, Maryland, USA.

Cochran, W. G. 1977. Sampling techniques. 3rd edition, J. Wiley, New York, NY USA.

Gibbs, J. P. 1998. Integrating monitoring objectives with sound sampling design: a pilot review of selected monitoring programs at Shenandoah National Park. Final Report to USDI, National Park Service.

Gerard, P. D., D. R. Smith, and G. Weerakkody. 1998. Limits of retrospective power analysis. Journal of Wildlife Management 801-807.

Gerrodette, T. 1993. TRENDS: Software for a power analysis of linear regression. Wildlife Society Bulletin 21:515-516

Kreuger, J. A., and R. L. Rich. 2001. Using PDAs for data collection. Bulletin of the Ecological Society of America 82:128-129.

Mahan, C. 2000. Vegetation inventory and monitoring workshop for Shenandoah National Park: setting objectives and priorities. Summary Report of Workshop Outcomes, USDI, National Park Service.

Shenandoah National Park. 1991. Natural resource inventory and long-term ecological monitoring system plan for Shenandoah National Park.

Smith, D. W. and J. L. Torbert. 1990. Shenandoah National Park long-term ecological monitoring system. Section II. Forest components user manual. NPS/NRSHEN/NRTR-90/02.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring vertebrate populations. Academic Press, New York, New York, USA.

Uquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246-257.

Appendix A. Change in mean basal area (m^2/ha) and total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type, Shenandoah National Park, 1987-2000.

Species	Forest cover type	Mean change (m^2/ha)	CV (%)	80% CI			Total Change (m^2)	80% CI		
Red oak species	Cove hardwoods	-0.66	66	-1.37	–	0.05	-7,621	-15,853	–	-611
	Pine	0.71	61	0.05	–	1.38	3,048	195	–	5,902
	Chestnut oak	-2.23	39	-3.48	–	-0.98	-84,592	-132,148	–	-37,035
	Black locust	0.01	75	0.00	–	0.02	24	-6	–	54
	Northern red oak	-4.31	28	-6.02	–	-2.60	-31,835	-44,473	–	-19,197
	Yellow poplar	0.11	76	-0.05	–	0.27	1,342	-571	–	3,254
All oak species	Cove hardwoods	-2.51	64	-5.54	–	0.53	-29,112	-64,358	–	6,134
	Pine	0.06	425	-0.30	–	0.42	255	-1,276	–	1,785
	Chestnut oak	-3.17	26	-4.30	–	-2.04	-120,485	-163,327	–	-77,643
	Black locust	0.00	240	-0.01	–	0.02	11	-32	–	53
	Northern red oak	-6.39	15	-7.66	–	-5.12	-47,173	-56,552	–	-37,794
	Yellow poplar	-0.03	548	-0.39	–	0.32	-417	-4,735	–	3,900
Northern red oak	Cove hardwoods	-0.43	66	-1.37	–	0.05	-7,621	-15,853	–	611
	Pine	-0.22	157	-0.49	–	0.20	-614	-2,093	–	865
	Chestnut oak	-0.88	38	-3.58	–	-1.06	-87,951	-135,840	–	-40,063
	Black locust	0.01	75	0.00	–	0.02	24	-6	–	54
	Northern red oak	-1.21	28	-6.06	–	-2.62	-32,051	-44,725	–	-19,377
	Yellow poplar	0.08	92	-0.07	–	0.25	1,086	-791	–	2,963
White oak species	Cove hardwoods	-1.54	84	-4.74	–	1.07	-21,322	-55,045	–	12,401
	Pine	0.12	68	0.00	–	0.36	765	0	–	1,530
	Chestnut oak	-0.86	97	-2.10	–	0.33	-33,579	-79,720	–	12,562
	Black locust	0.00					0			
	Northern red oak	-0.95	42	-3.61	–	-0.92	-16,729	-26,674	–	-6,783
	Yellow poplar	0.03	87	-0.02	–	0.09	392	-253	–	1,036

Appendix A. Change in mean basal area (m^2/ha) and total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type, Shenandoah National Park, 1987-2000. (continued)

Species	Forest cover type	Mean change (m^2/ha)	CV (%)	80% CI			Total Change (m^2)	80% CI		
Yellow poplar	Cove hardwoods	0.15	50	0.04	–	0.26	1,709	439	–	2,978
	Pine	0.06	132	-0.06	–	0.18	251	-255	–	757
	Chestnut oak	0.06	76	0.00	–	0.12	2,261	-156	–	4,678
	Black locust	0.18	20	0.11	–	0.25	575	354	–	796
	Northern red oak	0.04	100	-0.03	–	0.12	327	-208	–	862
	Yellow poplar	2.51	43	0.98	–	4.04	30,220	11,822	–	48,618
Red maple	Cove hardwoods	-0.29	109	-0.89	–	0.30	-3,376	-10,291	–	3,539
	Pine	0.61	43	0.11	–	1.12	2,633	476	–	4,790
	Chestnut oak	0.56	86	-0.93	–	2.05	21,322	-35,336	–	77,980
	Black locust	0.05	165	-0.10	–	0.20	155	-328	–	639
	Northern red oak	0.19	35	0.10	–	0.28	1,384	724	–	2,044
	Yellow poplar	0.12	76	-0.02	–	0.25	1,399	-235	–	3,032
Virginia and pitch pine	Pine	-11.19	26	-15.69	–	-6.69	-47,979	-67,274	–	-28,683
Black locust	Cove hardwoods	-0.28	40	-0.43	–	-0.12	-3,228	-5,014	–	-1,441
	Pine	-0.07	104	-0.20	–	0.06	-291	-858	–	277
	Chestnut oak	-0.13	66	-0.28	–	0.03	-4,813	-10,807	–	1,180
	Black locust	-0.71	50	-1.30	–	-0.13	-2,278	-4,144	–	-412
	Northern red oak	-0.08	87	-0.19	–	0.03	-602	-1,405	–	202
	Yellow poplar	-0.90	58	-1.76	–	-0.04	-10,830	-21,161	–	-498
Black birch	Cove hardwoods	-0.47	43	-0.80	–	-0.14	-5446	-9,271	–	-1,621
	Pine	0.26	52	0.00	–	0.51	1,107	20	–	2,193
	Chestnut oak	0.12	75	-0.01	–	0.25	4,505	-376	–	9,386
	Black locust	0.02	204	-0.09	–	0.12	53	-278	–	384
	Northern red oak	0.05	79	-0.01	–	0.11	394	-54	–	841
	Yellow poplar	-0.18	121	-0.54	–	0.18	-2,205	-6,564	–	2,155

Appendix B. Total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000.

		First sampling period				Second sampling period			
Species	Forest cover type	Total basal area (m^2)	CV (%)	80% CI		Total basal area (m^2)	CV (%)	80% CI	
Red oak species	Cove hardwoods	34,386	70	12,254 –	96,492	26,764	89	7,697 –	93,071
	Pine	6,417	60	2,743 –	15,009	9,465	60	4,067 –	22,030
	Chestnut oak	252,463	31	164,274 –	387,996	163,239	50	82,968 –	321,175
	Black locust	96	66	36 –	258	120	68	44 –	330
	Northern red oak	114,822	33	73,123 –	180,299	82,987	34	51,725 –	133,142
	Yellow poplar	3,608	100	755 –	17,244	4,950	92	1,135 –	21,589
All oak species	Cove hardwoods	72,593	49	30,170 –	174,670	43,481	69	13,442 –	140,647
	Pine	21,211	63	9,346 –	48,139	21,466	63	9,483 –	48,592
	Chestnut oak	1,110,439	9	977,229 –	1,261,807	987,472	13	826,223 –	1,180,190
	Black locust	466	76	154 –	1,405	477	71	168 –	1,355
	Northern red oak	176,444	14	145,704 –	213,670	129,271	21	97,524 –	171,352
	Yellow poplar	11,297	29	6,562 –	19,449	10,880	51	4,400 –	26,900
Northern red oak	Cove hardwoods	34,386	70	12,254	96,492	26,764	89	7,697 –	93,071
	Pine	2,434	68	950 –	6,234	1,820	76	647 –	5,120
	Chestnut oak	234,259	37	140,725 –	389,961	141,676	56	66,729 –	300,799
	Black locust	96	66	36 –	258	120	68	44 –	330
	Northern red oak	109,026	35	67,880 –	175,113	76,975	37	46,627 –	127,078
	Yellow poplar	3,608	100	755 –	17,244	4,694	98	997 –	22,107

Appendix B. Total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000. (continued)

		First sampling period					Second sampling period				
Species	Forest cover type	Total basal area (m^2)	CV (%)	80% CI			Total basal area (m^2)	CV (%)	80% CI		
White oak species	Cove hardwoods	38,039	64	12,616	–	114,693	16,717	92	3,830	–	72,960
	Pine	11,235	70	4,425	–	28,528	12,001	69	4,802	–	29,993
	Chestnut oak	784,385	15	634,108	–	970,275	752,956	18	582,436	–	973,399
	Black locust	0					0				
	Northern red oak	59,874	51	30,395	–	117,941	43,145	53	21,381	–	87,060
	Yellow poplar	5,539	80	1,472	–	20,842	5,930	80	1,566	–	22,454
Yellow poplar	Cove hardwoods	11,684	86	3,893	–	35,066	13,392	87	4,416	–	40,611
	Pine	262	100	73	–	940	513	100	143	–	1,838
	Chestnut oak	21,100	92	6,942	–	64,135	23,361	96	7,479	–	72,969
	Black locust	3,905	22	2,607	–	5,848	4,480	18	3,185	–	6,300
	Northern red oak	318	100	81	–	1,245	645	100	165	–	2,523
	Yellow poplar	236,810	22	174,124	–	322,064	267,030	25	187,569	–	380,153
Red maple	Cove hardwoods	30,564	82	7,861	–	118,844	27,189	78	7,463	–	99,050
	Pine	3,099	84	784	–	12,258	5,732	80	1,520	–	21,621
	Chestnut oak	52,908	74	6,876	–	407,078	73,855	77	9,102	–	599,297
	Black locust	3,342	56	1,251	–	8,927	3,007	59	1,079	–	8,377
	Northern red oak	5,194	45	2,897	–	9,314	6,578	46	3,601	–	12, 015
	Yellow poplar	23,468	42	12,731	–	43,261	24,867	43	13,294	–	46,516

Appendix B. Total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000. (continued)

		First sampling period					Second sampling period				
Species	Forest cover type	Total basal area (m^2)	CV (%)	80% CI			Total basal area (m^2)	CV (%)	80% CI		
Virginia and pitch pine	Pine	73,806	27	42,585	–	106,959	23,572	63	7,843	–	48,535
Black locust	Cove hardwoods	32,768	62	14,764		72,727	29,540	63	13,211		66,050
	Pine	1,205	68	375	–	3,874	915	100	190	–	4,396
	Chestnut oak	19,257	80	5,116	–	72,476	14,443	84	3,625	–	57,533
	Black locust	39,389	5	36,280	–	42,765	36,959	8	32,550	–	41,966
	Northern red oak	3,361	84	1,102	–	10,248	2,759	100	770	–	9,888
	Yellow poplar	19,784	56	8,376	–	46,728	8,954	72	3,108	–	25,792
Black birch	Cove hardwoods	24,795	52	11,200	–	54,892	19,349	66	7,272	–	51,483
	Pine	2,122	70	647	–	6,955	3,228	69	1,002	–	10,392
	Chestnut oak	12,810	80	4,633	–	35,419	16,971	86	5,805	–	49,611
	Black locust	398	114	24	–	6,617	650	100	50	–	8,425
	Northern red oak	3,186	73	1,240	–	8,183	3,580	71	1,424	–	8,995
	Yellow poplar	17,474	65	6,624	–	46,088	15,269	61	6,105	–	38,185

Appendix C. Mean change in stems/ha for shrub and sapling (1-5 m tall) species or species group, by forest cover type, Shenandoah National Park, 1987- 2000.

Species	Forest cover type	Mean change (stems/ha)	CV (%)	80% CI
Ash species	Cove hardwoods	-63.1	58	-132 – 6
	Pine	56.3	87	-36 – 149
	Chestnut oak	1.7	194	-3 – 6
	Black locust	-16.1	141	-53 – 21
	Northern red oak	-5.5	1169	-105 – 94
	Yellow poplar	-284.2	63	-577 – 8
Flowering dogwood	Cove hardwoods	0.0		
	Pine	-484.5	55	-920 – -49
	Chestnut oak	-137.2	59	-290 – 16
	Black locust	-135.6	31	-214 – -57
	Northern red oak	-94.0	61	-203 – 15
	Yellow poplar	-321.3	53	-581 – -62
Spicebush	Cove hardwoods	1,130.1	38	427 – 1,833
	Pine	240.8	100	-128 – 610
	Chestnut oak	13.9	205	-27 – 55
	Black locust	444.0	37	174 – 714
	Northern red oak	61.1	126	-65 – 187
	Yellow poplar	2,873.2	49	544 – 5,202
Sassafrass	Cove hardwoods	-7.2	100	-21 – 6
	Pine	201.3	58	30 – 372
	Chestnut oak	215.2	46	69 – 362
	Black locust	208.3	57	-159 – 572
	Northern red oak	4.2	573	-33 – 42
	Yellow poplar	-10.8	197	-43 – 22

Appendix C. Mean change in stems/ha for shrub and sapling (1-5 m tall) for each species or species group, by forest cover type, Shenandoah National Park, 1987- 2000. (continued)

Species	Forest cover type	Mean change (stems/ha)	CV (%)	80% CI
Rubus spp.	Cove hardwoods	61.6	77	-28 – 151
	Pine	425.3	62	45 – 806
	Chestnut oak	881.4	77	-1,198 – 2,961
	Black locust	351.8	50	62 – 642
	Northern red oak	4,112.9	65	265 – 7,960
	Yellow poplar	111.6	88	-50 – 273
Mountain laurel	Cove hardwoods	0.0		
	Pine	508.8	71	-1,334 – 2,351
	Chestnut oak	331.3	38	115 – 507
	Black locust	0.0		
	Northern red oak	167.2	76	-12 – 346
	Yellow poplar	-35.3	100	-93 – 23
Scrub oak	Pine	-199.2	97	-470 – 71

Appendix D. Stem density (stems/ha) for shrub and sapling (1-5 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000.

		First sampling period			Second sampling period		
Species	Forest cover type	Stems/ha	CV (%)	80% CI	Stems/ha	CV (%)	80% CI
Ash species	Cove hardwoods	157.3	49	66 – 376	94.2	48	40 – 222
	Pine	18.7	100	4 – 89	74.9	90	18 – 320
	Chestnut oak	46.1	71	18 – 116	47.8	71	19 – 120
	Black locust	97.0	25	65 – 145	88.9	32	53 – 148
	Northern red oak	174.6	33	106 – 287	169.0	51	81 – 352
	Yellow poplar	405.1	55	175 – 936	120.9	41	63 – 231
Flowering dogwood	Cove hardwoods	15.7	50	8 – 30	15.7	50	8 – 30
	Pine	536.1	57	225 – 1,275	51.6	100	13 – 202
	Chestnut oak	270.1	42	127 – 576	132.9	48	56 – 313
	Black locust	202.8	15	153 – 269	67.2	46	30 – 153
	Northern red oak	278.9	47	120 – 649	184.9	41	89 – 386
	Yellow poplar	329.5	50	159 – 681	8.3	100	2 – 30
Spicebush	Cove hardwoods	463.8	28	296 – 727	1,593.9	32	959 – 2,650
	Pine	0.0			240.8	100	67 – 862
	Chestnut oak	12.7	82	5 – 36	26.7	100	8 – 88
	Black locust	521.7	79	166 – 1,640	553.3	39	300 – 1,022
	Northern red oak	30.5	46	15 – 62	91.6	94	25 – 338
	Yellow poplar	1,490.3	41	783 – 2837	4,363.5	43	2,238 – 8,508
Sassafrass	Cove hardwoods	14.4	100	3 – 69	7.2	100	2 – 35
	Pine	138.3	58	62 – 306	339.6	34	208 – 554
	Chestnut oak	250.4	42	139 – 452	465.6	40	263 – 825
	Black locust	69.9	81	8 – 617	306.0	66	48 – 1,958
	Northern red oak	78.2	48	39 – 157	82.4	73	30 – 226
	Yellow poplar	24.7	60	11 – 58	13.9	72	5 – 37

Appendix D. Stem density (stems/ha) for shrub and sapling (1-5 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000. (continued)

		First sampling period			Second sampling period		
Species	Forest cover type	Stems/ha	CV (%)	80% CI	Stems/ha	CV (%)	80% CI
Rubus species	Cove hardwoods	0.0			61.6	77	17 – 223
	Pine	0.0			425.3	62	187 – 968
	Chestnut oak	0.0			881.4	77	109 – 7,144
	Black locust	26.4	75	9 – 79	378.2	46	185 – 772
	Northern red oak	26.8	100	8 – 89	4,139.8	65	1,762 – 9,727
	Yellow poplar	39.0	88	11 – 134	150.6	54	66 – 346
Mountain laurel	Cove hardwoods	0.0			0.0		
	Pine	2,228.2	35	1,168 – 4,249	1,804.5	32	1,321 – 5,673
	Chestnut oak	1,116.3	35	696 – 1,792	1,638.1	33	1,046 – 2,566
	Black locust	0.0			0.0		
	Northern red oak	344.2	66	146 – 810	511.4	49	267 – 981
	Yellow poplar	35.3	100	9 – 138	0.0		
Scrub Oak	Pine	360.9	58	171 – 762	161.7	54	79 – 330

Appendix E. Mean change in stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type, Shenandoah National Park, 1987-2000.

Species	Forest cover type	Mean change (stems/ha)	CV (%)	80% CI
Northern red oak	Cove hardwoods	-207.4	105	-879 – 464
	Pine	-182.7	283	-1,158 – 793
	Chestnut oak	-2,222.6	53	-3,972 – -473
	Black locust	-522.0		[a]
	Northern red oak	631.2	314	-2,110 – 3,373
	Yellow poplar	197.0	235	-514 – 908
White oak species	Cove hardwoods	-66.7	100	-192 – 59
	Pine	2,363.9	33	1,265 – 3,463
	Chestnut oak	-5,225.6	42	-8,203 – -2,248
	Black locust	348.0		[a]
	Northern red oak	-1,027.1	83	-2,336 – 282
	Yellow poplar	-318.1	100	-839 – 203
Oak species	Cove hardwoods	-395.0	60	-839 – 49
	Pine	5,106.7	67	42 – 10,171
	Chestnut oak	-7,114.7	44	-11,892 – 2,338
	Black locust	-174.0		[a]
	Northern red oak	552.0	465	-2,972 – 4,076
	Yellow poplar	131.3	379	-632 – 895
Red maple	Cove hardwoods	13,185.5	64	296 – 26,075
	Pine	10,976.9	55	-444 – 22,398
	Chestnut oak	16,175.1	42	5,856 – 26,494
	Black locust	-7,583.9	97	-22,169 – 6,461
	Northern red oak	3,164.2	95	-1,772 – 8,100
	Yellow poplar	3,794.2	123	-3,112 – 10,701

Appendix E. Mean change in stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type, Shenandoah National Park, 1987-2000. (continued)

Species	Forest cover type	Mean change (stems/ha)	CV (%)	80% CI
Ash species	Cove hardwoods	3,278.7	69	65 – 6,492
	Pine	842.4	92	-430 – 2,114
	Chestnut oak	235.1	145	-255 – 725
	Black locust	-17,496.3	2	-17,967 – -17,026
	Northern red oak	-1,295.0	73	-2,739 – 149
	Yellow poplar	-958.8	200	-3,782 – 1,864
Birch species	Cove hardwoods	399.9	215	-1,221 – 2,021
	Pine	-1715.5	166	-6,379 – 2,948
	Chestnut oak	632.5	175	-1,182 – 2,447
	Black locust	0.0		
	Northern red oak	2573.3	83	-712 – 5,859
	Yellow poplar	-954.2	64	-1,951 – 43
Yellow poplar	Cove hardwoods	1,528.8	72	-280 – 3,338
	Pine	139.8	100	-74 – 354
	Chestnut oak	2,816.5	68	-3,110 – 8,743
	Black locust	230.5	251	-718 – 1,179
	Northern red oak	687.8	73	-130 – 1,506
	Yellow poplar	274.4	315	-1,051 – 1,599
Flowering dogwood	Cove hardwoods	81.5	100	-72 – 235
	Pine	-3,845.7	69	-8,820 – 1,128
	Chestnut oak	941.6	63	118 – 1,765
	Black locust	1,589.3	5	1,448 – 1,731
	Northern red oak	-1,185.2	117	-3,808 – 1,437
	Yellow poplar	-2,140.7	86	-4,949 – 668

Appendix E. Mean change in stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type, Shenandoah National Park, 1987-2000. (continued)

Species	Forest cover type	Mean change (stems/ha)	CV (%)	80% CI
Mountain laurel	Cove hardwoods	0.0		
	Pine	-38,099.5	78	-86,568 – 10,369
	Chestnut oak	-4,399.6	108	-11,210 – 2,411
	Black locust	0.0		
	Northern red oak	1,120.3	47	121 – 2,12
	Yellow poplar	0.0		
Vaccinium species	Cove hardwoods	0.0		
	Pine	-98,466.1	52	-173,000 – 23,528
	Chestnut oak	18,680.4	88	-31,753 – 69,113
	Black locust	0.0		
	Northern red oak	-2,927.0	224	-12,621 – 6,767
	Yellow poplar	0.0		
Rubus species	Cove hardwoods	730.0	149	-942 – 2,402
	Pine	11,869.5	43	4,462 – 19,277
	Chestnut oak	3,241.1	49	232 – 6,250
	Black locust	10,148.4	8	8,949 – 11,348
	Northern red oak	5,784.5	32	3,210 – 8,359
	Yellow poplar	4,482.5	38	1,939 – 7,026

[a]No standard error could be estimated because there was no replication of plots in the strata in which stems were counted.

Appendix F. Stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000.

		First sampling period			Second sampling period		
Species	Forest cover type	Stems/ha	CV (%)	80% CI	Stems/ha	CV (%)	80% CI
Northern red oak	Cove hardwoods	841.9	55	173 – 4,105	634.6	65	101 – 3,980
	Pine	604.3	80	160 – 2,281	421.6	64	141 – 1,265
	Chestnut oak	3,593.4	37	2,122 – 6,084	1,357.3	35	820 – 2,247
	Black locust	696.0		[a]	174.0		[a]
	Northern red oak	4,693.6	21	3,524 – 6,251	5,324.8	36	3,284 – 8,633
	Yellow poplar	446.2	58	196 – 1,015	643.2	60	275 – 1,503
White oak species	Cove hardwoods	66.7	100	14 – 320	0.0		
	Pine	5,411.8	66	2,322 – 12,614	7,775.7	50	4,003 – 15,104
	Chestnut oak	19,999.3	23	14,666 – 27,272	14,760.2	24	10,652 – 20,453
	Black locust	0.0		[a]	348.0		[a]
	Northern red oak	5,375.3	48	2,681 – 10,777	4,348.2	49	2,132 – 8,869
	Yellow poplar	466.8	75	156 – 1,397	148.7	100	38 – 581
Oak species	Cove hardwoods	1,029.6	48	440 – 2,411	634.6	65	206 – 1,955
	Pine	7,826.5	47	4,060 – 15,087	12,933.1	39	7,391 – 22,630
	Chestnut oak	24,660.0	24	17,193 – 35,370	17,518.3	22	12,598 – 24,360
	Black locust	696.0			522.0		
	Northern red oak	10,994.1	32	7,183 – 16,828	11,546.1	30	7,718 – 17,272
	Yellow poplar	1,220.7	46	623 – 2,391	1,352.0	28	890 – 2,053

Appendix F. Stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000. (continued)

		First sampling period			Second sampling period		
Species	Forest cover type	Stems/ha	CV (%)	80% CI	Stems/ha	CV (%)	80% CI
Red maple	Cove hardwoods	3,171.8	70	1,205 – 8,346	16,357.3	52	7,733 – 34,600
	Pine	5,521.2	57	2,025 – 15,053	16,498.2	53	6,507 – 41,830
	Chestnut oak	6,527.2	22	4,686 – 9,092	22,715.7	32	14,157 – 36,448
	Black locust	13,032.2	71	3,880 – 43,776	6,034.8	34	3,248 – 11,213
	Northern red oak	3,985.4	22	2,783 – 5,708	7,149.6	53	3,183 – 16,058
	Yellow poplar	12,940.6	26	8,932 – 18,749	16,734.9	31	10,660 – 26,271
Ash species	Cove hardwoods	6,710.0	39	3,959 – 11,372	9,988.7	25	7,090 – 14,073
	Pine	982.2	80	309 – 3,120	1,824.6	85	542 – 6,137
	Chestnut oak	479.3	60	216 – 1,064	714.4	60	323 – 1,582
	Black locust	21,948.6	2	21,390 – 22,522	4,595.0	6	4,160 – 5,076
	Northern red oak	3,765.1	34	2,283 – 6,208	2,470.2	45	1,282 – 4,760
	Yellow poplar	78,62.1	35	4,747 – 13,022	6,903.3	26	4,729 – 10,077
	Cove hardwoods	1,298.5	68	406 – 4,158	1,698.4	96	370 – 7,790
	Pine	3,394.0	92	945 – 12,183	1,678.5	40	897 – 3,141
	Chestnut oak	1,118.6	29	702 – 1,782	1,724.2	67	638 – 4,657
	Black locust	571.0	100	181 – 1,803	0.0		
	Northern red oak	1,760.1	96	510 – 6,078	4,333.4	88	1,353 – 13,883
	Yellow poplar	954.2	64	366 – 2,485	0.0		
Yellow poplar	Cove hardwoods	162.9	100	42 – 636	1,691.8	69	608 – 4,705
	Pine	0.0			139.8	100	39 – 501
	Chestnut oak	106.6	63	18 – 635	2,923.1	66	457 – 18,697
	Black locust	586.8	59	239 – 1,440	960.1	60	387 – 2,383
	Northern red oak	0.0			687.8	73	237 – 1,997
	Yellow poplar	737.6	87	233 – 2,339	1,012.0	51	482 – 2,123

Appendix F. Stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000. (continued)

		First sampling period					Second sampling period				
Species	Forest cover type	Stems/ha	CV (%)	80% CI			Stems/ha	CV (%)	80% CI		
Flowering dogwood	Cove hardwoods	0.0					81.5	100	17	–	391
	Pine	4,000.5	69	1,231	–	13,003	154.8	100	32	–	743
	Chestnut oak	985.4	59	457	–	2,124	1,927.0	43	1,083	–	3,429
	Black locust	150.6	50	62	–	366	1,740.0		[a]		
	Northern red oak	5,738.7	34	3,053	–	10,787	4,553.5	13	3,574	–	5,801
	Yellow poplar	2,935.8	55	1,329	–	6,485	795.1	100	222	–	2,849
Mountain laurel	Cove hardwoods	0.0					0.0				
	Pine	43,779.1	69	15,754	–	121,657	5,679.6	42	2,936	–	10,988
	Chestnut oak	8,031.9	60	3,608	–	17,878	3,632.4	33	2,272	–	5,807
	Black locust	0.0					0.0				
	Northern red oak	1,267.4	46	553	–	2,904	2,387.7	44	1,086	–	5,250
	Yellow poplar	0.0					0.0				
Vaccinium species	Cove hardwoods	0.0					0.0				
	Pine	176,973.9	36	36	–	106,336	78,507.8	27	52,927	–	116,452
	Chestnut oak	41,484.5	58	58	–	7,875	60,164.9	66	9,356	–	386,906
	Black locust	0.0					0.0				
	Northern red oak	20,589.2	33	33	–	12,749	17,662.2	39	10,080	–	30,948
	Yellow poplar	0.0					0.0				

Appendix F. Stem density (stems/ha) for seedling (<1 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000. (continued)

		First sampling period			Second sampling period		
Species	Forest cover type	Stems/ha	CV (%)	80% CI	Stems/ha	CV (%)	80% CI
Rubus species	Cove hardwoods	1,375.1	86	440 – 4,293	2,105.1	36	1,239 – 3,577
	Pine	3,965.9	71	1,579 – 9,960	15,835.4	40	9,137 – 27,444
	Chestnut oak	196.2	71	59 – 652	3,437.3	45	1,519 – 7,778
	Black locust	2,414.4	31	1,538 – 3,790	12,848.3	9	11,210 – 14,726
	Northern red oak	1,179.8	49	615 – 2,262	6,964.3	30	4,610 – 10,521
	Yellow poplar	1,340.5	67	547 – 3,288	5,823.0	37	3,415 – 9,928

[a]No standard error could be estimated because there was no replication of plots in the strata in which stems were counted.

Appendix G. Mean change in stem density (stems/ha) of saplings and seedlings for tree-of-heaven (*Ailanthus altissima*), Shenandoah National Park, 1987-2000.

Size class	Forest cover type	Mean change (stems/ha)	CV (%)	80% CI
Mountain laurel	Cove hardwoods	0.0		
	Pine	-38,099.5	78	-86,568 – 10,369
	Chestnut oak	-4,399.6	108	-11,210 – 2,411
	Black locust	0.0		
	Northern red oak	1,120.3	47	121 – 2,123
Saplings	Cove hardwoods	143.0	80-	32 – 318
	Pine	0.0		
	Chestnut oak	20.7	71	-1 – 43
	Black locust	55.7	70	-18 – 130
	Northern red oak	3.8	100	-2 – 10
	Yellow poplar	110.2	64	6 – 215
Seedlings	Cove hardwoods	-3,368.2	75	-7,499 – 762
	Pine	1,398.4	69	-77 – 2,874
	Chestnut oak	-7.7	4,372	-504 – 489
	Black locust	-119.7	2,170	-5,016 – 4,777
	Northern red oak	206.4	74	-29 – 442
	Yellow poplar	-1,976.3	213	-8,185 – 4,233

Appendix H. Stem density (stems/ha) of tree-of-heaven (*Ailanthus altissima*) for saplings (1-5 m tall) and seedlings (<1 m tall) by forest cover type and sampling period, Shenandoah National Park, 1987-2000.

		First sampling period			Second sampling period		
Size class	Forest cover type	Stems/ha	CV (%)	80% CI	Stems/ha	CV (%)	80% CI
Saplings	Cove hardwoods	21.7	100	6 – 78	164.7	64	67 – 403
	Pine	0.0			0.0		
	Chestnut oak	0.0		–	20.7	71	8 – 53
	Black locust	4.2	100	1 – 20	59.9	72	18 – 203
	Northern red oak	0.0			3.8	100	1 – 15
	Yellow poplar	34.1	63	14 – 80	144.3	58	65 – 320
Seedlings	Cove hardwoods	5,288.0	78	1,709 – 16,360	1,919.8	88	553 – 6,668
	Pine	0.0			1,398.4	69	538 – 3,633
	Chestnut oak	266.5	100	78 – 910	258.8	74	98 – 686
	Black locust	4,137.3	64	1,367 – 12,520	4,017.6	19	2,795 – 5,774
	Northern red oak	0.0			206.4	74	75 – 571
	Yellow poplar	5,297.9	75	1,981 – 14,167	3,321.5	77	1,216 – 9,076

Appendix I. Percent cover, by species, pre-treatment (1998-99) and post-treatment (2000) in Big Meadows, Shenandoah National Park.

Species	Pre-treatment			Post-treatment		
	% cover	CV (%)	85% CI	% cover	CV (%)	85% CI
Wetland only						
Panicled dogwood	16.2	55.4	8.17 – 32.14	4.56	62.0	2.94 – 9.71
Hazelnut spp.	0.66	74.5	0.27 – 1.60	0.09	100.0	0.03 – .28
Broadleaf meadowsweet	18.46	54.9	9.34 – 36.48	0.45	98.5	0.15 – 1.33
Upland only						
Black locust	0.15	75.9	0.06 – 0.33	0.03	81.2	0.01 – 0.06
Wetland and Upland						
Hawthorn spp	0.39	67.3	0.18 – 0.89	0.01	100.0	0.00 – 0.05
Black huckleberry	0.55	53.6	0.29 – 1.01	0.24	93.2	0.09 – 0.63
Maleberry	4.70	21.6	3.63 – 6.08	1.97	31.2	1.37 – 2.84
Rubus spp	0.01	77.0	0.00 – 0.02	0.03	100.0	0.01 – 0.08
Upland low blueberry	1.95	31.2	1.36 – 2.82	0.04	81.3	0.02 – 0.09
Squaw huckleberry	7.45	18.6	5.97 – 9.30	2.27	26.8	1.65 – 3.11
All shrub spp.	20.92	12.3	18.03 – 24.27	5.80	17.4	4.72 – 7.00

Appendix J. Mean decline in percent cover (paired-plot differences), by species and for all species combined, from pre-treatment (1998-99) to post-treatment (2000) in Big Meadows, Shenandoah National Park.

Species	Mean decline in % cover	CV (%)	85% CI
Wetland Only			
Panicled dogwood	11.60	53.6	1.80 – 21.40
Hazelnut spp.	0.60	71.7	-0.10 – 1.20
Broadleaf meadowsweet	18.00	54.2	2.60 – 33.40
Upland Only			
Black locust	0.12	95.0	-0.09 – 0.33
Wetland and Upland			
Upland low blueberry	1.92	31.9	0.81 – 3.03
Hawthorn spp.	0.38	70.6	-0.15 – 0.92
Squaw huckleberry	5.18	22.4	3.07 – 7.30
Black huckleberry	0.31	118.8	-0.36 – 0.98
Maleberry	2.73	33.1	1.08 – 4.37
Rubus spp.	-0.02	125.8	-0.08 – 0.03
All shrub spp.	15.12	13.5	11.30 – 18.90